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THE THEORY OF ICE MACHINES.

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II.

§ 21. THE principle of these machines is the same as that of the kind described in the last chapter. The gas is compressed, then deprived of its heat, and finally caused to expand in such a manner as to lower its temperature. Only in this instance the abstraction of the heat which follows the compression, has the effect to liquefy the gas, and it is the vaporization of the resulting liquid which produces the lowering of the temperature.

When a change of volume of a saturated vapor is made under constant pressure, the temperature remains constant. The addition or subtraction of heat, which produces the change of volume, is represented by an increase or a diminution of the quantity of liquid mixed with the vapor.

On the other hand when vapors, even if saturated, are no longer in contact with their liquids, and receive an addition of heat, either through compression by a mechanical force, or from some external source of heat, they comport themselves nearly in the same way as permanent gases, and become superheated.

It results from this property, that refrigerating machines, using a liquefiable gas will afford results differing according to the method of working, and depending upon the state of the gas, whether it remains constantly saturated, or is superheated during a part of the cycle of working.

§ 22. We will suppose first that the gas is constantly saturated and will examine the conditions to be fulfilled under this hypothesis, and the results that may be obtained.

Employing the notation of the preceding chapter we will designate by m the weight of the gas employed, P_2 and T_2, the pressure and the absolute temperature of the cooled gas, P_1 and T_1', the pressure and the absolute temperature in the condenser.

The pressures P_2 and P_1 are determined by the temperatures T_2 and T_1'; These are the pressures of a saturated vapor at these temperatures, and are given in Regnault's tables.

The temperature of the condenser is determined beforehand by local conditions. Depending on the surface, the interior of the condenser will exceed by 5° or 10° the temperature of the water furnished to the exterior. This latter will vary from 11° or 12° C the temperature of water from considerable depth below the surface, to 30° or 35°, the temperature of surface water in hot climates. The volatile liquid employed in the machine ought not at this temper-

ature to have a tension above that which can be readily managed by the apparatus.

On the other hand if the tension of the gas at the minimum temperature is too low, it becomes necessary to give to the compression cylinder large dimensions, in order that the weight of vapor afforded by a single stroke of the piston shall be sufficient to produce a notably useful effect.

These two conditions, to which may be added others; such as those depending on the greater or less facility of obtaining the liquid, upon the dangers incurred in its use either from its inflammability or unhealthfulness, and finally upon its action upon the metals, limit the choice to a small number of substances.

The gases or vapors in use, are; Sulphuric Ether, Sulphurous Oxide, Ammonia and Methylic Ether.

The following table derived from Regnault exhibits the tensions of the vapors of these four substances at different temperatures between $-30°$ and $+40°$. The original tables expressed the tensions in millimeters of mercury. To facilitate computation, the tensions are here given in *kilograms per square meter.*

Temperature.	Sulpuric Ether.	Sulphur Dioxide.	Ammonia.	Methylic Ether.
°				
−40	—	—	7.187	—
−35	—	—	9.302	—
−30	—	3.908	11.918	7.837
−25	—	5.082	15.120	9.736
−20	917	6.519	19.003	11.992
−15	1.194	8.265	23.669	14.652
−10	1.541	10.366	29.225	17.765
− 5	1.968	12.874	35.797	21.380
0	2.493	15.840	43.475	25.547
+ 5	3.129	19.322	52.405	30.318
+10	3.894	23.378	62.707	35.743
+15	4.808	28.074	74.504	41.873
+20	5.891	33.474	87.925	48.755
+25	7.164	39.645	103.073	56.437
+30	8.651	46.659	120.083	64.961
+35	10.377	54.585	129.054	—
+40	12.367	63.496	160.112	—

An inspection of the table shows at once that the use of ether does not readily lead to the production of low temperatures because its pressure becomes then very feeble.

The ether machine is, however, abandoned. Ammonia on the contrary is well adapted to the production of low temperatures; but its elastic force is very great at temperatures from 15° to 30° which are readily produced in the condenser. It is not a good aid to the transformation of mechanical force into heat, on account of the difficulty of maintaining tight joints in the apparatus, and of the influence of waste spaces at the high pressures. Methylic ether yields low temperatures without attaining too great pressures at the temperature of the condenser. Finally, sulphur dioxide readily affords temperatures of $-10°$ to $-15°$ while its pressure is only 3 to 4 atmospheres at the ordinary temperature of the condenser. These two latter substances then lend themselves conveniently for the production of cold by means of mechanical force.

§ 23. Let c be the specific heat of the liquid employed.

q the quantity of heat necessary to raise 1 kilogram of the liquid from 0° to $T°-273°$.

$$q=c(T-273)$$

λ, r, ρ, the total heat, the heat of vaporization, and the latent heat of the vapor considered at the temperature $T°-273$.

u, the increase of volume of one kilogram of liquid vaporizing at $T°-273°$.

We have by definition

$$\lambda=r+q$$
$$\rho=r=APu.$$

We will apply indices to these quantities similar to those which affect the letter T in designating the different absolute temperatures.

In order that the vapor be constantly saturated, it is necessary that the quantities of liquid and of vapor taken into the compressor at once be such that at the end of the compression all the liquid shall be vaporized and the vapor shall not be superheated.

If we let x'_2, represent the proportion of vapor contained in the mixture at the commencement of the inflow, the work of compression will be equal to the difference in the amount of internal heat of the mixture at the beginning and end of

the compression, that is to say to $m(q_1'-q_2+\rho_1'-x_2'\rho_2)$.

The work of the inflow into the condenser will be $P_1 V_1$, calling V_1' the volume occupied by a weight m of the vapor at the end of the compression, and the work of the back pressure will be $P_2 V_2$, V_2 being the volume occupied by the weight mx_2' of vapor.

We have also

$$V_1'=m\left(u'_1+\frac{0{,}001}{\delta}\right).$$

and
$$V_2=mx'_2\left(u_2+\frac{0{,}001}{\delta}\right), \qquad (75)$$

δ being the density of the liquid supposed constant.

We may neglect the fraction which is very small, and write

$$V'_1=mu'_1,$$
$$V_2=mx'_2u_2,$$

from which we may get

$$mr'_1=m\rho'_1+AP_1V'_1$$
and
$$mr_2=m\rho_2+AP_2V_2.$$

The total work of the compression including the outflow is

$$AW_r=m(q'_1-q_2+r'_1-x'_2r_2). \qquad (76)$$

As the compression follows an adiabatic curve, the quantities q'_1, q_2, r'_1, r_2, T'_1 and T_2 bear the following relation:

$$\int_{T_2}^{T'_1}\frac{cdt}{T}=\frac{x'_2r_2}{T_2}-\frac{r'_1}{T'_1}$$

or more simply,

$$\frac{r'_1}{T'_1}+cl\frac{T'_1}{T_2}=\frac{x'_2r_2}{T_2}. \qquad (77)$$

Equation (77) will give the quantity x'_2. Consequently equation (75) furnishes, when we know m the volume V_2 that the piston should describe during the aspiration in order that all the liquid should be vaporized at the end of the compression; or, inversely, the weight m may be found if V_2 be given.

The vapor flows into the condenser where it is liquefied.

The heat absorbed by the water of the condenser is

$$Q_1=mr'_1 \qquad (78)$$

The liquid, then passes into the expansion cylinder where it is vaporized, producing work till it attains the pressure P_2 and the temperature T_2 of the refrigerant. At the end of the expansion, the weight of vapor in the mixture is mx_2.

The work, including the counter-pressure, and neglecting the work of introducing the liquid, $p_1\frac{0.00.1.m}{\delta}$, which is very small, is;

$$AW_m=m(q'_1-q_2-x_2r_2). \qquad (79)$$

and the equation of the adiabatic curve is

$$\frac{x_2r_2}{T_2}=cl\frac{T'_1}{T_2} \qquad (80)$$

which determines x'_2.

The quantity of heat Q necessary to bring the mixture whose weight is $m(1-x_2)$ of liquid and mx_2 of vapor to its primitive condition, in which $m(1-x'_2)$ is the weight of the liquid and mx'_2 is the weight of the vapor, is,

$$Q=m(x'_2-x_2)r_2$$

or by reason of equations (76) and (79)

$$Q=\frac{T_2}{T'_1}mr'_1 \qquad (81)$$

The work expended is W_r-W_m and we have

$$A(W_r-W_m)=m[r'_1-(x'_2-x_2)r_2]=Q_1-Q. \qquad (82)$$

The theoretic performance of the machine is

$$\frac{Q}{W_r-W_m}=\frac{AQ}{Q_1-Q}=A.\frac{T_2}{T'_1-T_2} \qquad (83)$$

a result already found in section 3, and which is identical with that at which we arrived in the case of permanent or non-liquefiable gases.

§ 24. We will now take a numerical example, and consider the dimensions of the cylinders to be so regulated that a final temperature of $-15°$ is obtained, the temperature of the condenser being $+18°$, and the volume of gas taken into the compressor at each stroke, V_2=one cubic meter.

The resolution of the above equations supposes a knowledge of the values of r, q, c and u, or APu. They have been determined directly by Regnault for sulphuric ether, but not for sulphur dioxide, ammonia and methylic ether. Availing ourselves of the experiments of Regnault upon the compressi-

bility of gases, we have been able to determine these quantities for sulphur dioxide and ammonia and prepare tables giving results for every five degrees from $-30°$ to $+40°$.

The method of calculation of these tables will be found in a note at the end of this essay.

For sulphur dioxide we find,

$t_2=-15$ or $T_2=258$	$t'_1=+18$ or $T_2=291$
$r_2=$ 95.015	$r'_1=$ 87.23
$AP_2u_2=7.932$	$AP_1u'_1=8.568$
$q_2=-5.4615$	$q'_1=6.554$
$u_2=$ 0.419	$u'_1=0.1165$

The table of § 22 gives $P_2=8265$ and $P_1=31170$.

Making the calculations indicated by the equations (77) and (80) we find

$$x'_2=93.29 \text{ per cent.}$$
$$x_2=11.90 \text{ per cent.}$$

Equation (75) gives

$$m=2.554 \text{ kilograms.}$$

Equations (76) and (79) give

$AW_r=27.08$ whence $W_r=11.482$ k'g'm.
$AW_m=1.82$ whence $W_m=$ 772 k'g'm.

Finally equations (78) and (81) give

$$Q_1=222.77$$
$$Q=197.56$$

Thus the volume described by the piston of the compression cylinder being one cubic meter, 2^k,554 of sulphur dioxide working between $-15°$ and $+18°$ produce 197.50 negative calories. To effect this it is necessary to introduce into the compressor cylinder at each stroke a mixture of liquid and gas of which the proportion should be 93.29 per cent. of gas and 6.71 per cent. of liquid.

We have for ammonia

$t_2=-15°$	$t'_1=+18°$
$P_2=$ 23669	$P'_1=$ 82183
$r_2=$ 322.53	$r'_1=$ 301.70
$AP_2u_2=$ 28.604	$AP_1u'_1=$ 31.431
$u_2=$ 0.512	$u'_1=$ 0.1621
$q_2=-14.68$	$q'_1=$ 18.696

The mean specific heat of the liquid at $0°$, $c=1.0058$.

By means of these given values we find

$x'_2=92.62$ per cent.
$x'_2=$ 9.68 per cent.
$m=$ 2^k.1034

$AW_r=$ 76.55	$W_r=32,457$ k'g'm
$AW_m=$ 4.52	$W_m=$ 1,917 k'g'm

$Q_1=634.59$
$Q=562.56$

2^k.1034 of ammonia working between the same limits of $+18°$ and $-1°$ and with the same dimensions of compressor cylinder as before furnish 562.56 negative calories per hour.

We will now consider ether. The vapor of ether, unlike steam, superheats during expansion and condenses during compression. An ether machine ought, therefore, to work so that only vapor is introduced into the compressor cylinder, and not a mixture of liquid and vapor. At the end of the compression a part of the vapor becomes condensed.

We shall then have $x'_2=1$ and the equations above found become:

$$V'_1=mx'_1\left(u'_1+\frac{0,001}{\delta}\right),$$

$$V'_2=m\left(u_2+\frac{0,001}{\delta}\right),$$

$$\frac{x'_1r'_2}{T_2}=\frac{r_2}{T_2}-c\,.\,l\,\frac{T'_1}{T_2},$$

$$\frac{x_2r_2}{T_2}=cl\,\frac{T'_1}{T_2},$$

$$Q_1=mx'_1r'_1,$$

$$Q=m(1-x_2)r_2,$$

$$AW_r=m(q'_1-q_2+x'_1r'_1-r_2),$$

$$AW_m=m(q'_1-q_2-x_2r_2).$$

The empirical formulas established by Regnault for the vapor of ether are:

$$r=94,00-0,0790t-0,0008514t^2,$$
$$APu=7,46+0,02747t-0,001354t^2,$$
$$q=0,52901t+0,0002959t^2.$$

and we deduce:

for $t=-15$	and $t=+18$,
$P_2=1194$ kilog.	$P_1=5456$,
$r_2=94963$,	$r_1=92,302$,
$AP_2u_2=7,014$,	$AP_1u_1=7,516$,
$u_2=2,491$,	
$q_2=-7.868$,	$q_1=9,618$,
	$c=0,5299$,

and we have $\delta=0,736$.

Performing the calculations indicated, we find,

$x_2 = 17.35$,
$x'_2 = 100$,
$x'_1 = 95.64$,
$m = 0.401$,
$Q_1 = 35^c.40$,
$Q = 31^c.38$,

$AW_r = 4.44$, $W_r = 1882^{kgm}$.
$AW_m = 0.42$, $W_m = 178^{kgm}$.

The same machine working between $-15°$ and $+18°$, will give per cubic meter of—

Ammonia..... 562.56 negative calories.
Sulphur dioxide. 197.56 "
Sulphuric ether. 31.38 "

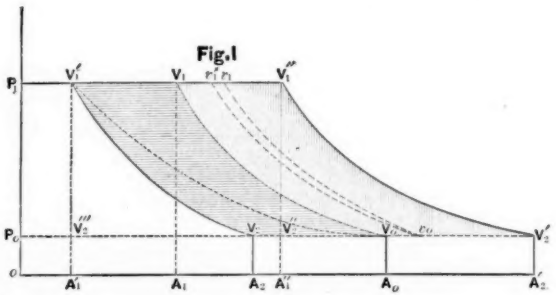
The efficiency would be $0^c,0184$ per kilogrammeter.

§ 25. We remark here that the positive work W_m is always small compared with the negative work W_r.

We can then without great loss of power simplify the machine by suppressing the expansion cylinder and replacing it by a simple cock so regulated as to deliver into the cooler a quantity of liquid precisely equal to the amount admitted to the compressor to obtain the determined cooling effect.

The cycle of operations is not reversible. We shall have $\frac{Q}{AW_r} = \frac{Q}{Q_1 - Q}$, but the proportion $\frac{Q}{Q_1 - Q}$ will be less than $\frac{T_2}{T'_1 - T_2}$, and the efficiency would be less.

This manner of working is represented in the diagram, Fig. 1, by replacing the adiabatic line $V'_1 V_2$ by the two right lines $V'_1 V'''_2$ and $V''_2 V_2$ situated to the right of the point V_2. The quantity Q



proportioned to $V''_2 V_0$ is less than the quantity Q of the preceding case which was proportioned to $V_2 V_0$, and the quantity $Q_1 - Q$ will be augmented by a quantity proportional to the area $V'_1 V''' V_2$.

The equations (76), (77) and (78) remain unchanged.

The weight m of the liquid under the pressure P_1 and the temperature T'_1 passing suddenly into the refrigerator, a part of the liquid is vaporized; the temperature of the mixture becomes T_2 and the pressure P_2. The quantity x_2 of liquid, which is vaporized, is given by the equation

$$m(q_2 - q'_1 + x_2\rho_2) + AP_2V'_2 - A(P_1 - P_2)\frac{0.001.m}{\delta} = 0,$$

which shows that the variation of internal heat $m(q_2 - q'_1 + x_2\rho_2)$ is equal to the exterior work accomplished;

$$-AP_2V'_2 + A(P_1 - P_2)\frac{0.001.m}{\delta};$$

V'_2 being the volume occupied by the weight mx_2 of vapor after the passage of the mixture into the refrigerant.

We have $V'_2 = mx_2\left(u_2 + \frac{0.001}{\delta}\right)$.

If we neglect the very small quantity

$$AP_1\frac{0.001\,m}{\delta}$$

the preceding equation becomes:

$$x_2 r = q'_1 - q_2 \qquad (84)$$

The quantity Q is again given by the equation

$$Q = m(x'_2 - x_2)r_2$$

or by reason of eq. (76)

$$Q = mr'_1 - AW_r = Q_1 - AW_r$$

from whence the performance

$$\frac{Q}{W_r} = A\frac{Q}{Q_1 - Q} \qquad (85)$$

The efficiency will be less. It is easy to show that the value of x_2 given by eq. (84) is always greater than that given by eq. (80). Consequently the value of Q will be less in the second case than in the first, and the ratio $\frac{Q}{Q_1 - Q}$ will also be less.

In applying equations (84) and (85) to the same cases as those of § 24, we find for sulphur dioxide

$$x_2 = 12.64 \text{ per cent.}$$
$$Q = 195.71$$

and the performance $= 0.^c0170$ per kilogrammeter. For ammonia:

$$x_2 = 10.35 \text{ per cent.}$$
$$Q = 558.11$$

and the efficiency $0.^c0172$.

Finally for sulphuric ether

$$x_2 = 18.46 \text{ per cent.}$$
$$Q = 30.96$$

efficiency $= 0.^c0164$

§ 26. In order to realize, either the cycle of Carnot or the non-reversible cycle indicated above, it is necessary, when we employ a liquefiable gas which superheats under compression, to introduce into the compressor cylinder at each aspiration, a mixture of liquid and vapor in such proportions that it shall all be in the state of gas at the end of the compression.

We can devise no practical means of realizing this condition. So we content ourselves when employing freezing machines that use a liquefiable gas, with introducing into the compressor the gas without any mixture of liquid. It happens then with sulphur dioxide and ammonia that the gas superheats during compression, and therefore that during a part of the operation the machine acts like the air machine.

It is clear that under these conditions we augment the range of temperature between T_1 of the gas arriving in the condenser, and T_2 of the refrigerant, and consequently of the useful effect of the apparatus.

Referring again to Fig. 1 we see that we start with a volume v_0 greater than V_0 of the preceding case, compress the vapor to the volume v_1 following the adiabatic curve v_0v_1 of the superheated gas; cool it from the temperature T_1 to the temperature T_1' corresponding to its liquefaction under the pressure P_1. It is then passed into the refrigerant either producing work and describing the adiabatic curve V_1V_2 or by means of a cock by which means it describes the lines $V_1'V_2''''$ and $V_2'''V_2''$.

The quantity of negative heat gained by superheating is represented by the length V_0v_0 and the increase of resistant work by the area $V_0V_1v_1v_0$.

Tracing from the point v_0 the adiabatic curve of the saturated vapor, the point v_1' will be to the left of v_1.

If the compressed vapor follows the adiabatic v_0v_1', the performance $\frac{Q'}{Q_1' - Q}$ will be equal to the performance $\frac{Q}{Q_1 - Q}$ of the cycle $V_0V_1V_1'V_2$.

But as the compression follows the line v_0v_1 we see that for the same quantity Q' of obtainable negative heat, the quantity $Q_1 - Q$ would be greater than a quantity proportional to the area v_0vv'.

We can say, then, that *a priori*, the theoretic efficiency of freezing machines working so as to superheat the gas is less than that of machines that work without superheating.

The difference is small as we shall see later.

§ 27. We will now examine the conditions of working of a machine, under the supposition that we introduce into the cylinder during aspiration only gas, and in such condition as to superheat during compression.

A certain volume V_2 of gas under pressure P_2 and temperature T_2, it is required to find its volume V_1 and its temperature T_1 when it shall have attained the pressure P_1 of the condenser.

If liquefiable gases behaved as do permanent gases, it would suffice to use the equations (1) to (6), which were established in § 10 for the compression of air.

But the researches of Regnault on the compressibility of gases, have established the fact that when near the liquefying

point these bodies are far from following the laws of Mariotte and Gay Lussac upon which the formulas which we have used were founded.

Zeuner has given (Théorie Mécanique de la Chaleur) the result of his researches upon superheated steam.

He found the following relation to exist between the pressure P, the volume of the unit of weight (specific volume) v, and the absolute temperature T,

$$P_v = BT - CP^n \qquad (86)$$

in which C and n are constants to be determined by experiment

$$B = \frac{C_p n}{A} \qquad (87)$$

C_p being the specific heat of the vapor under constant pressure, which is constant according to Regnault.

If we make $k = \frac{4}{3}$, B=50.933 and C=192.50, we find that this formula furnishes for the specific volume of steam, numbers which agree remarkably well with the results of experiment.

Zeuner does not offer this relation as rigorously exact, but as giving much better results than the formula,

$Pv = RT$ which applies to permanent gases.

Liquefiable gases being nothing but superheated vapors, we will employ equation (84) established for superheated steam, but will determine the constants in each case employing the results of Regnault's experiments upon the dilatation and compression of gases.

If we call a the coefficient of dilatation of the gas under atmospheric pressure, it is easy to see that eq. (86) gives:

$$a = \frac{1}{273 - \frac{C}{B} . 10.334^n}$$

and $$10.334 v_0 = 273B - C . 10334^n, \qquad (88)$$

whence $$10.334 v_0 a = B. \qquad (89)$$

an equation which gives B when we know the coefficient of dilatation and specific volume v_0 at 0° and atmospheric pressure.

If the relation (87) were exact, it would suffiice with equations (88) and (89) for determining B, C and n. But the numbers thus obtained do not coincide, at least in the case of sulphur dioxide and ammonia with the results obtained by Regnault. Instead therefore of using equation (87) we will determine n by one of the results found by Regnault for the product PV.

Regnault gives values of PV for temperatures of 1.7° for sulphur dioxide, for 8.1° for ammonia and for pressures varying from 600 to 1200 and 1400 millimeters of mercury. We can deduce from these tables the volume V_0 at 0° and under pressure of 760 millimeters, and then calculate the weight m of the gas required in our examples. We then have

$$PV = mBT - mCP^n \qquad (90)$$

which combined with equation (89) will furnish C and n.

For sulphur dioxide

$$a = 0.0039028; \quad v_0 = 0.3442$$

For $P = 16.345^{kgm.}$ and $T = 274.7$.

Regnault found,

$$\frac{PV}{m} = 3526.16$$

We deduce B=13.882
C=3.8455
n=0.44487

Introducing these constants into equation (86) we can obtain for Pv values which coincide in a satisfactory manner with Regnault's results.

These values are slightly less than Regnault's for pressures between 10.334 kg. and 16.345 kg., and a little larger for pressures lying beyond these limits on either side.

For ammonia we unfortunately do not know the coefficient of dilatation; it was not determined by Regnault. As this gas is near its liquefying point at 0° we will assume it coefficient to be about the same as that sulphur dioxide and cyanogen, which is 0.0039. In the absence of exact values determined by experiment it is clear that results obtained under the above assumption can be regarded as approximative only.

We have $v_0 = 1.2977$ and Regnault's tables give:

$\frac{PV}{m} = 13596$ for T=281.1° and P=19515 kgm.

We then deduce

B=52.4943, C=43.7144, n=0.32685,

§ 28. It remains now to find the equation of the adiabatic curve of a superheated

vapor, of which the pressure, the specific volume and the temperature are related as follows:

$$pv=BT-Cp^n.$$

The fundamental equation of the mechanical theory of heat is, calling Q the quantity of heat furnished to a body, U its internal work, and supposing the external pressure is always equal to the expansive force:

$$dQ=A(dU+pdv),$$

and as U is a function of p and v, we have:

$$dQ=A\left\{\frac{dU}{dP}dp+\left(\frac{dU}{dv}+p\right)dv\right\}.$$

Assuming $\frac{dU}{dp}=X$ $\frac{dU}{dv}+p=Y$,

we have $$dQ=A\,(Xdp+Ydv) \qquad (91)$$

or $$dQ=AT\left(\frac{x}{T}dp+\frac{Y}{T}dv\right)$$

and since dU is an exact differential,

$$\frac{dX}{dv}=\frac{dY}{dp}-1.$$

We know that the factor $\frac{1}{T}$ is the factor of integrability of the function $Xdp+Ydv$; and we deduce

$$T=Y\frac{dt}{dp}\,X\frac{dt}{dv} \qquad (92)$$

We also have in virtue of equation (86),

$$\frac{dt}{dp}=\frac{v}{B}+\frac{nCp^{n-1}}{B}$$

and $$\frac{dt}{dv}=\frac{p}{B}.$$

If we suppose that the pressure remain constant, $dp=0$, and eq. (91) gives

$$dQ_p=AY\,dv.$$

But, $dQ_p=c_p dt$, calling c_p the specific heat at constant pressure, which we suppose constant and which is known. We have then:

$$Y=\frac{c_p}{A}\frac{dt}{dv}=\frac{c_p}{A}\frac{p}{B}$$

and from eq. (92),

$$X=-\frac{BT}{p}+\frac{c_p}{AB}(v+nCp^{n-1})$$

and finally,

$$dQ=A\left\{\frac{c_p}{AB}(pdv+vdp)-vdp+\left(\frac{nc_p}{AB}-1\right)Cp^{n-1}dp\right\} \qquad (93)$$

For the equation of an adiabatic curve, it is necessary to make $dQ=0$. We have then:

$$\left(\frac{c_p}{AB}-1\right)dpv+pdv+\left(\frac{nc_p}{AB}-1\right)Cp^{n-1}dp=0. \qquad (94)$$

Introducing the value of T from equation (86), it becomes.

$\frac{c_p}{AB}\frac{dt}{T}=\frac{dp}{p}$ and integrating $\frac{c_p}{AB}lT=lp$ + const.

or finally

$$\left(\frac{T}{T_0}\right)^{\frac{c_p}{AB}}=\frac{p}{p_0}, \qquad (95)$$

an equation analogous to equation (4) which we found for air.

Replacing T by this value in equation (86) we get finally for the equation of the adiabatic curve

$$pv=BT_0\left(\frac{p}{p_0}\right)^{\frac{AB}{c_p}}-Cp^n. \qquad (96)$$

If $\frac{AB}{c_p}$ be equal to n, as Zeuner admits, for superheated steam, this equation becomes $pv_k=$a constant, and it is similar to that which represents the adiabatic curve of the permanent gases.

Eq. (94) gives the work of compression

$$pdv=-dW\left(1-\frac{c_p}{AB}\right)dpv+\left(1-\frac{nc_p}{AB}\right)Cp^{n-1}dp$$

whence

$$W=\left(\frac{c_p}{AB}-1\right)(pv-p_0v_0)+\left(\frac{c_p}{AB}-\frac{n}{1}\right)C(p^n-p_0^n) \qquad (97)$$

or again

$$W=\left(\frac{c_p}{AB}-1\right)B(T-T_0)+C\left(1-\frac{1}{n}\right)(p^n-p_0^n) \qquad (98)$$

and

$$W=\left(\frac{c_p}{AB}-1\right)B(T-T_0)+C\frac{1-\frac{1}{n}}{p_0^n}\left\{\left(\frac{T}{T_0}\right)^{\frac{nc_p}{AB}}-1\right\} \qquad (99)$$

§ 29. We can now establish the equations relating to the compression of a

liquefiable gas in a cylinder. A weight m of gas occupying the volume V_2 at the temperature T_2, and under the pressure P_2 is compressed until the pressure is P_1 of the condenser. The temperature T_1 at the end of the compression will be given by the equation (95).

$$T_1 = T_2\left(\frac{P_1}{P_2}\right)^{\frac{AB}{c_p}} \qquad (100)$$

and the work of compression including the flowing of the the gas is

$$\left.\begin{aligned} W_r &= \frac{mc_p}{AB}(P_1V_1 - P_2V_2) + m\left(\frac{AB}{c_p} - \frac{1}{n}\right) \\ &\quad C(P_1^n - P_2^n) \\ \text{or} \\ W_r &= \frac{mc_p}{A}(T_1 - T_2) - \frac{mcP_2^n}{n}\left\{\left(\frac{T_1}{T_2}\right)^{\frac{nc_p}{AB}} - 1\right\} \end{aligned}\right\} \qquad (101)$$

m is given by the equation

$$m = \frac{P_2V_2}{BT_2 - CP_2^n} = \frac{V_2}{u_2 + \frac{0.001}{\delta}} \qquad (102)$$

the final volume

$$V_1 = V_2\frac{P_2}{P_1}\cdot\frac{BT_1 - CP_1^n}{BT_2 - CP_2^n}.$$

We cool the gas in the condenser under constant pressure. The volume V_1 becomes V_1' at the moment the temperature becomes T_1'; since the gas is liquefied we have;

$$V_1' = V_2\frac{P_2}{P_1}\cdot\frac{BT_1' - CP_1^n}{BT_2 - CP_2^n}$$

and the quantity of heat removed from the condenser is:

$$Q_1 = mc_p(T_1 - T_1') + mr_1' \qquad (103)$$

The volume occupied by the liquid is

$$v_1 = \frac{0.001.m}{\delta}$$

δ being the density of the liquid supposed constant.

The liquid is then passed into the refrigerant without producing work.

The quantity mx_2 of gas which vaporizes while the pressure passes from P_1 to P_2 and the temperature from T_1' to T_2 is by equation (84);

$$mx_2r_2 = m(q_1' - q_2).$$

The quantity of negative heat obtained is:

$$Q = m(1-x_2)r_2$$

or

$$Q = m(\lambda_2 - q_1') \qquad (104)$$

and we have

$$Q_1 - Q = mc_p(T_1 - T_1') + m(r_1' + q_1' - r_2 - q_2)$$

or

$$Q_1 - Q = mc_p(T_1 - T_1') + m(\lambda_1' - \lambda_2)$$

We can verify the equality $Q_1 - Q = AW_r$ or

$$\lambda_1' - \lambda_2 = c_p(T_1' - T_2) - \frac{AC}{n}(P_1^n - P_2^n)$$

Referring to the fundamental equation

$$dQ = AdU + APdv$$

and making $dQ = 0$ it becomes

$$mdU = -mPdv = -dW$$

and consequently

$$U_1 - U_2 = \left(\frac{C_p}{AB} - 1\right)B(T_1 - T_2) + C\left(1 - \frac{1}{n}\right)(P_1^n - P_2^n) \qquad (105)$$

We have furthermore by definition,

$$\lambda = AU + APv,$$

an equation which signifies that the total heat of the vapor at $t°$ is equal to the internal heat AU augmented by the thermal equivalent of the work of vaporization and dilatation.

We have then

$$\lambda_1 - \lambda_2 = C_p\,(T_1 - T_2) - \frac{AC}{n}(P_1^n - P_2^n)$$

This equation is applicable to a superheated vapor above its point of saturation.

It applies also at the point of saturation; we have then

$$\lambda_1' - \lambda_2 = C_p\,(T_1' - T_2) - \frac{AC}{n}(P_1^n - P_2^n) \qquad (106)$$

which verifies the equation

$$Q_1 - Q = AW_r.$$

Equation (105) can be written:

$$U - U_0 = \left(\frac{C_p}{AB} - 1\right)(Pv - P_0v_0) + \left(\frac{C_p}{AB} - \frac{1}{n}\right)C(P^n - P_0^n)$$

If we make $\frac{C_p}{AB} - \frac{1}{n} = 0$.

the equation becomes

$$U = U_0 + \frac{1-n}{n}(Pv - P_0v_0)$$

Under this form it expresses Hirn's law of superheated vapors, and may be thus expressed:—from the point of con-

densation, to the point at which the superheated vapor possesses the same properties as the permanent gases, the product pv remains constant while the internal work remains the same.

But the equation

$$\frac{c_p}{AB}=\frac{1}{n}$$

is not verified for the cases of the two liquefiable gases which we have studied, and consequently we cannot apply to them the law of Hirn.

§ 30. We will now take a numerical example and suppose as in the preceding case, that a cubic meter of gas is admitted at the temperature of $-15°$ under a pressure corresponding to this temperature, and that it is compressed until its tension is that of the condenser and that the temperature of this latter is, in the interior, $+18°$.

Sulphur dioxide. Equation (102) gives

$$m=\frac{1}{0.419+\frac{0.001}{1.412}}=2^k.382$$

Equation (100) gives; making

$$c_p=0.15438$$

after Regnault, and

$$\frac{AB}{c_p}=0.211882;$$

$$T_1=T_2\left(\frac{P_1}{P_2}\right)^{0.211882}=334.31 \qquad \text{or} \quad t_1=68°.80$$

Equations (103) and (104) give

$$Q_1=227.49$$
$$Q=197.75$$

whence $AW_r=Q_1-Q=28.71$

and $W_r=121.75$

and the theoretic performance $=0.^c0162$ or 4.374 calories per horse power per hour.

In a double acting engine working at high velocity we estimate the resistances at about 15 per cent. of the power expended.

$1.15W_r=13.998$ and the performance becomes $0.^c0141$ or 3.807 calories per horse power, per hour.

This performance is double that of the machine working with dry air between the same limits of temperature. This difference shows not that the air is theoretically a less efficient agent in the production of cold, but that to produce the same useful effect, the air machine having much larger dimensions than the liquefiable gas machines will experience proportionally greater loss through resistances.

§ 31. Generally with sulphur dioxide we do not get as low a temperature as $-15°$.

The opening of the cock which leads from the condenser to the cooler is so regulated that the pressure in the latter is about $\frac{9}{10}$ of an atmosphere which corresponds to a temperature of $-12°.41$.

$$P_2=9301 \text{ kg.} \quad t_2=-12°.41.$$

With these values the tables, given at the end of this memoir, give

$$m=\frac{1}{v_2}=2^k.784$$
$$r_2=94.377$$
$$q_2=-4.517$$
$$u_2=0.3863$$

and by means of equations (100), (102), (103) and (104) of § 29 it is easy to calculate T_1, Q_1, Q and W_r.

The results of these calculations are recorded in the following table, which gives the negative heat obtained, the work absorbed and the performance per cubic meter of sulphur dioxide, supposing the apparatus regulated for a temperature of $-12°41$ in the refrigerant, and that the temperature of the interior of the condenser varies from $+15°$ to $+40°$:

(*See Table on following page.*)

We see that the performance diminishes more than one-half when the temperature of the interior of the condenser rises from 15° to 40°.

The figures of the last column do not nearly represent the number of calories really produced and utilized. It is necessary to take into account the loss occasioned by the pipes; the waste spaces in the cylinder; of loss of time in opening of the valves; of the leakage around the piston and valves; of the reheating by the external air; and finally, when ice is being made, of the quantity of the ice melted in removing the blocks from their molds.

It requires about 100 calories to congeal to $-7°$ a kilogram of water taken at 15° or 16°. Manufacturers estimate that practically the sulphur dioxide apparatus using water at 12° or 13°, produces 25 kilograms of ice, or 2,500 calo-

Temperature of condenser, inside.	Pressure corresponding P_1	Temperature after compression, t_1.	Heat absorbed by water of the condenser.	Negative heat.	Theoretical work of compression.	Work including passive resistances.	Negative calories developed.			
							Per theoretic kilogrammeter.	Per theoretic horse power per hour.	Per effective kilogrammeter.	Per effective horse power per hour.
degrees	kilog.	degrees	cal.	cal.	kgm.	kgm.	cal.	cal.	cal.	cal.
15	28,074	56.20	243.35	218.09	10,735	12,335	0.02031	5.484	0.01768	4.774
20	33,474	68.69	243.19	213.38	12,444	14,310	0.01715	4.630	0.01491	4.026
25	39,645	81.15	243 04	208.66	14,609	16,890	0.01428	3.856	0.01242	3.353
30	46,659	93.56	242.80	203.94	16,515	19,022	0.01235	3.334	0.01072	2.894
35	54,585	105.93	242.56	199.21	18,425	21,189	0.01081	2 919	0.00940	2.538
40	63,496	118.26	242.27	194.48	20,312	23,359	0.00957	2.584	0.00832	2.246

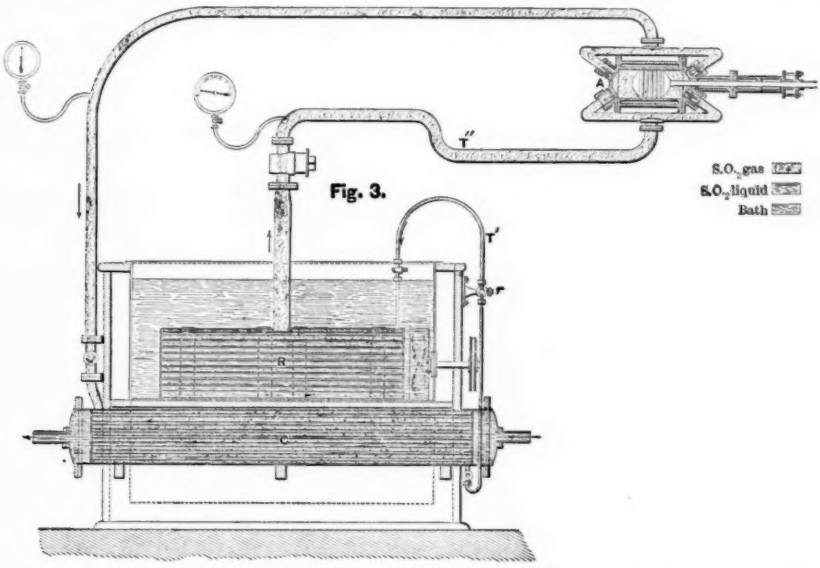


Fig. 3.

ries per horse power per hour, measured on the driving shaft, which is about 55 per cent. of the theoretic efficiency indicated above.

Fig. 3 represents the Pictet machine from a design furnished us by the inventor. It has a double-acting compression cylinder with four valves. The cylinder is furnished with a jacket, within which a current of cold water is made to circulate.

The gas is compressed to a tension corresponding to the temperature of the water employed for cooling, generally 1.8 to 2 kilograms effective pressure; then it is discharged by the pipe T into the condenser C where it is liquefied.

This condenser is like the surface condensers of marine engines. It has a surface of about 24 square meters for 100,000 *theoretic* calories per hour, or 48 square meters for 100,000 *effective* calories per hour measured by the ice produced.

The quantity of water employed depends upon the difference of temperature to be allowed between the inside and outside of the condenser.

If this difference is to be 5° each litre of water releases 5 calories and the

quantity of water to be employed will be for 100 theoretic calories produced

$$\frac{Q_1 100}{5Q} = 20\frac{Q_1}{Q}$$

which would require for the example of § 31 and for a temperature of 20° in the condenser, 22.8 litres.

The liquid dioxide passes into the refrigerant R by the pipe T′, the supply being regulated by the cock r so that the pressure shall be $\frac{9}{10}$ of an atmosphere in the refrigerant and 3 atmospheres in the condenser. If the outlet by the cock be diminished the pressure is lowered in the cooler, and the temperature is also lowered, but the useful effect also diminishes since for the same volume, described by the compressor piston, less weight of gas is used. We have in this machine, therefore, the same facilities for varying the useful effect as in the air machines.

The refrigerant is constructed like the condenser. Its surface is 29 square meters for each 100,000 theoretic negative calories produced per hour. It is immersed in an incongealable bath formed of a solution of calcium chloride.

The temperature of the interior of the refrigerant being −12°, that of the bath being −7°. In this bath are immersed the tanks or moulds within which the water is frozen.

Finally the sulphur dioxide returns to the compressor cylinder by the pipe T″.

The dioxide may be employed continuously so long as no air is permitted to enter the joints. Any leakage might lead to the production of the trioxide and possibly sulphuric acid which would lead to injury to machine. Exceptional care is required in maintaining tight joints.

Some experiments with an ammonia machine have not yielded very good resuls; but the want of success seems to have resulted rather from an imperfect action of the surface of the refrigerant than from any inherent defect in the gas itself. Ammonia gas prevents the advantage of affording about three times the useful effect as sulphur dioxide for the same volume described by the piston. But this advantage is balanced by the inconvenience of higher pressures and consequently more leakage, &c.

Between the limits of temperature of 12°.41 in the refrigerant and + 18° in the condenser we find for ammonia:

$P_2 = 26559$ kilos.
$r_2 = 321.06$
$u_2 = 0.461$
$q_2 = -1219$
and we have $C_p = 0.50836$
$\frac{AB}{C_p} = 0.242615.$

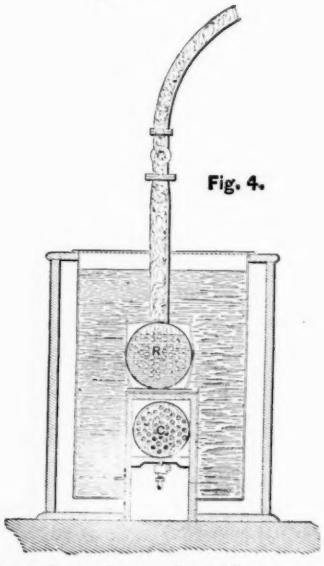


Fig. 4.

We deduce for each cubic meter described by the piston:

$m = 2.163$ k.
$T_1 = 342.75$ $t_1 = 69°.75$
$Q_1 = 709.48$
$Q = 627.03$
$AW_r = Q_1 - Q = 82.45$ $W_r = 34.959$ kg.

Theoretic efficiency: 0.0179 or 4.833 per horse power per hour.

Working the apparatus between −30° and +18° we find.

$P_2 = 11918k$
$r_2 = 330.48$
$u_2 = 0.9463$
$q_2 = -31.82$
$m = 1.0553k$
$T_1 = 388.20$ $t_1 = 115.20$
$Q_1 = 370.52$
$Q = 295.44$
$AW_r = Q_1 - Q = 75.08$ $W_r = 31.834$

Theoretic result: 0.00928 or 2505 per horse power per hour.

NOTES ON LOGARITHMS.

By MANSFIELD MERRIMAN, Professor in Lehigh University, Bethlehem, Penn.

Written for VAN NOSTRAND'S MAGAZINE.

LOGARITHMS were invented and brought into use by John Napier, a Scotch mathematician, who, in 1614, published at Edinburgh the first table. It consists of the natural sines for every minute of the quadrant with their logarithms, and the logarithms of the tangents. These were not what are now called Naperian logarithms; they depend on a base less than unity for they decrease as the sines increase. The following is a copy of a few lines from the top of the first page of this first table:

Gr. min	sinus	Logarithmi.	+ | − Differentiae.	Logarithmi.	Sinus.	
0	0	Infinitum.	Infinitum.	0	10000000	60
1	2909	81425681	81425680	1	10000000	59
2	5818	74494213	74494211	2	9999998	58

Here the sine of 0° 1′ is given as 2909 and its logarithm as 81425681; for 59° 58′, the sine is given as 9999998 and its logarithm as 2. The *differentiae* are the logarithms of the tangents.

Henry Briggs, a Professor of Geometry in London, was led by Napier's book to study the subject. He suggested the advantages which would arise from the choice of 10 as a base, and computed and published the first tables of common logarithms. His first book appeared in 1617, and contains common logarithms to fourteen decimals of the natural numbers from 1 to 1000. The second, published in 1624, contains logarithms also to fourteen decimals, of the numbers from 1 to 20,000 and from 90,000 to 100,000.

The first tables of Naperian logarithms (that is, logarithms to the base $e=2.71828+$) were published by John Speidell in 1619.

Edmund Gunter calculated and printed in 1620 the first table of the common logarithms of sines and tangents, and these were to seven decimals.

In 1628 Adrian Vlacq, a Belgian mathematician, republished Briggs' table to ten decimals and added the logarithms of the numbers from 20,000 to 90,000, thus completing the canon.

Briggs also calculated the ten-figure logarithms of the sines, tangents, etc., for every hundredth of a degree. These were published in 1633, after his death, by Vlacq, who also in the same year issued a similar work for every ten seconds of the quadrant. It thus appears that Briggs and Vlacq were the great logarithmic computers, and from their books nearly all modern tables have descended. A century and a-half afterwards (in 1792) Michael Taylor published a table of seven-figure logarithmic sines, tangents, etc., to every second, and about 1784 the French Government caused to be calculated anew extensive tables for the centesimal division of the quadrant, which have, however, never been printed.

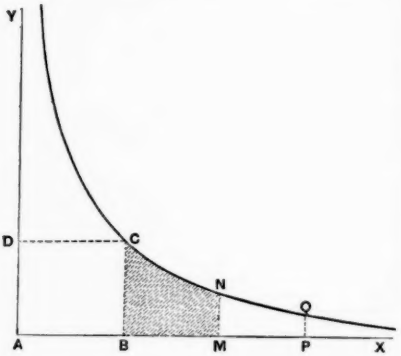
It is necessary to remark that neither Napier or Briggs, or any one until long after, had the idea of regarding logarithms as exponents. They seemed only to consider them as a series of numbers in arithmetical progression corresponding to another series in geometrical progression. Thus, in the two series,

1,	2,	4,	8,	16,	32,	64,	etc.
0,	1,	2,	3,	4,	5,	6,	

the position of the product of any two terms in the first will be pointed out by adding together the two corresponding terms in the second; for instance, $4\times16=14$ and $2+4=6$. Thus far, indeed, Archimedes saw fourteen centuries earlier, but to Napier belongs the great honor of distinctly conceiving how intermediate numbers could be taken in both of such series, so that the multiplication of any or all numbers might be abbreviated, and of executing the laborious task of computing a practical table.

In 1647 Gregory St. Vincent discovered the geometrical representation of logarithms by a hyperbola. To explain this, let the curve in the figure be one branch of an equilateral hyperbola, and let AY and AX be its asymptotes. Let

C be the vertex of the curve—a point such that the ordinates CB and CD form a square ABCD. Then St. Vincent showed that if distances AM, AP, etc., be laid off in geometrical progression that the hyperbolic areas BCNM, BCQP, etc., were in arithmetical progression.



From this it followed that if the area of the square, ABCD, were taken as unity the area, BCNM, would be numerically the Naperian logarithm of AM, wherever the line MN be drawn. For this reason the term "hyperbolic logarithms" was applied to the system whose modulus is unity, and the name is even now not unfrequently employed. The reason, however, is not a good one for these hyperbolic areas may represent the logarithms in any system provided that the square, ABCD, is taken as the modulus of the system; for instance, if the area of the square is 0.4342945 and AM be taken equal to unity, the area, MNQP, will be the common logarithm of AP. By the study of the properties of the hyperbola, it was hence possible to deduce relations between numbers and their logarithms. The well known logarithmic series

$$\text{Nap. log}\,(1+n)=\frac{n}{1}-\frac{n^2}{2}+\frac{n^3}{3}-\ldots.$$

was derived in this way.

Common and Naperian logarithms are the only ones with which engineers have to deal, and with the latter only rarely. Whenever a Naperian logarithm is needed it may be found by multiplying the common one by 2.3025851. In what precedes the word logarithm has been used in a general sense and as referring to all systems; in what follows it will be always understood to refer to the common system, namely, to the system whose base is 10.

A logarithm consists of two parts, a whole number and decimal. The latter is found recorded in the tables and the former, called the index, is supplied by the memory according to an easily recollected rule. This rule as given in the books is of a double character, one rule in fact for positive indices and another for negative indices. But some computers prefer to have but one rule, viz.: The index is found by counting the number of places by which the first significant figure of the number is removed from the units place, and it is positive when the first figure falls to the left of the units place but negative when it falls to the right. Thus 6583.2 has its first significant figure three places to the left of the units place and the index of its logarithm is 3, but 0.0065 has its first significant figure three places to the left and the index is -3.

It is often convenient to remember that the logarithm of 2 is 0.3 nearly. Then the one-figure logarithms of 4, 5 and 8 are at once known, and those of 3, 6, 7 and 9 may be easily inferred. But the computations made with one-figure logarithms are at the best only rough estimations. With a two-figure table, however, which can also be easily carried in the memory, a good many problems concerning powers and roots may be solved with some satisfaction. Here is a two-figure table of logarithms.

No.	Log.	No.	Log.
1	.00	6	.78
2	.30	7	.85
3	.48	8	.90
4	.60	9	.95
5	.70	10	.00

The index must always, of course, be supplied in accordance with the rule for indices. For instance, what is the square root of 0.3? Solution—. log. $0.3=-1+0.48$; divide this by 2 giving $-1+0.74$; hence the square root of 0.3 is about 0.55.

A table of three figure logarithms written on a card and kept on the office desk is often very serviceable. It is a double entry table giving directly the logarithms

of the natural numbers from 1 to 100, while those of the numbers up to 1000 may be taken out by interpolation.

Tables of four-figure logarithms may be had from the booksellers, printed on cards about 6×10 inches. They contain the 1000 logarithms of the first 1000 natural numbers, and are very handy for schools, as well as sufficiently precise for many practical calculations. It is related of one of our prominent astronomers, who is a very rapid computer, that he continually carries such a table in his memory.

Five-figure logarithms are precise enough for almost all common computations arising from measured data. The table, which embraces the first 10,000 natural numbers and occupies about twenty octavo pages, is a favorite one among computers on account of its compactness and its convenience in use. Here, as in the seven-figure tables, the proportional parts for interpolation are printed in full on the sides of the pages.

A six-figure table is universally employed in this country for school use. It is of the same length as the five-figure table, but has not the advantage of proportional parts, which cannot be inserted on account of the great number of differences. Since logarithms of five and seven figures are far more convenient, and are always used by computers, it seems desirable that the unhandy six-figure table should be banished from the schools.

Seven-figure tables are ten times as long as the five or six figure table and are extensively employed. There is no good American work, but a number of French and German books can be obtained at low prices.

Perhaps the only practical use of a ten-figure table would be in finding the compound interest on a large debt, such as might arise in transactions between nations. Vega's ten-figure table, published in 1794, is probably the most reliable and most easily accessible.

Logarithms of all the prime numbers up to 1097, to sixty-one decimals, are given in Callet's tables. Logarithms of all the natural numbers up to 109 were computed to one-hundred decimals, by H. M. Parkhurst, and published in his *Astronomical Tables*, New York, 1876. It is impossible for the mind of man to conceive of a practical case where so many decimals would be needed.

As a general rule it is often said that the number of accurate significant figures in the result of a computation is the same as the number of decimals in the logarithms employed. The following shows the results obtained by computing the cube-root of 6 with different tables, with and without interpolation:

No. of decimals in logarithms.	Cube root of 6 without interpolation.	Cube root of 6 with interpolation.
1	2.	1.9
2	2.	1.83
3	1.8	1.817
4	1.82	1.8171
5	1.817	1.81713
6	1.817	1.81712
7	1.8171	1.817121

As the correct value to eight places is 1.81712059 it appears that the above rule holds for this example in every instance when interpolation is employed. The example also shows that the five-place table gives relatively one more significant figure without interpolation than do the six and seven place tables.

In choosing a logarithmic table, then, regard should be had to the precision of the work, and in the case of calculations from data liable to errors of measurement the rule that the computation should be precise enough to introduce no additional errors ought to be rigidly observed. Yet the precision of the calculations should not be too far in advance of the measured data. What surveyor can, for instance, with ordinary tools, lay off a line twenty feet long accurate to the thousandth of a foot, or a line two hundred feet long accurate to the hundredth of a foot, or a line a mile long accurate to the tenth of a foot? Here the fifth figure of the measurements is certainly in error and five-figure logarithms are sufficiently precise; to use those of seven-figures would not only not be of advantage, but would consume valuable time and labor. A seven-figure table may, however, often be employed with profit to take out five-figure logarithms, for thus all interpolation will be avoided.

A cologarithm is a number which added to a logarithm makes 0; or co-log $n=0-\log n$. It is hence the logarithm of the

reciprocal of a number, and may be added whenever the logarithm itself is to be subtracted. Cologarithms save perhaps a little time and space to practiced computers, but they are generally of no assistance to beginning students.

The arithmetical complement of a logarithm is also a device whose office in textbooks is mainly to puzzle the young. It is equal to the cologarithm plus 10, and is used like the cologarithm except that as many 10's must be subtracted from the final logarithm as there have been arithmetical complements added. The books recommend its use to avoid negative indices, though why negative indices should be avoided by those who understand them, is not entirely apparent.

In most tables of the logarithms of the trigonometrical functions the indices have all been increased by 10 in order to render them positive. In using such tables this should be borne in mind and —2 written for 8, —1 for 9, 0 for 10, etc., or else as many 10's must be finally subtracted as there have been 10's added in the operation. It is more logical and more satisfactory to always use actual logarithms instead of those whose indices have thus been made positive, and it is pleasant to hear that in our best schools pupils are now taught that the index 8 in the tables means —2, that 9 means —1, and that 8 and 9 should never be used in calculations.

An antilogarithm is the number corresponding to a given logarithm, and an antilogarithmic table is a table from which the numbers can be directly taken, the logarithms being exact decimals and the numbers usually incommensurable. The following is a table of two-figure antilogarithms:

Log.	No.	Log.	No.
.0	10	.6	40
.1	13	.7	50
.2	16	.8	63
.3	20	.9	79
.4	25	.0	100
.5	32		

In using it the index of the given logarithm must, of course, be regarded. Such tables to more than three or four places are rather uncommon, since the ordinary table of logarithms is quite as convenient for finding numbers, and is usually preferred by computers.

The number of books relating to logarithms or containing logarithmic tables is now very great, amounting probably to several thousand. They range in size from the little pocket edition, or the table printed on a card, to the pondrous folio of Michael Taylor, which contains about 600 pages. Concerning the bibliography of the tables there has been something done, De Morgan, in the *English Cyclopædia*, having given a most interesting list abounding with historical information, a work which has been extended by the British Association for the Advancement of Science, in whose *Report* for 1873 can be found much matter of value. But the most complete bibliography is that of Bierens de Haan, published in the *Transactions* of the Amsterdam Academy for 1875, which enumerates 553 tables. Of these 178 appeared in Germany, 144 in England, 91 in France, 57 in Holland, 23 in Italy, and the remainder in eleven other countries; only 9 being given from the United States. Ninety-eight of them were published in the seventeenth century, 121 in the eighteenth, and 334 in the years 1801–1870. Tables of seven-figure logarithms were the most numerous, while those of five ranked next.

The Dercos Lines.—The great line of fortifications which constitute the permanent defences of Constantinople, and which have been entirely recast during the past winter under the superintendence of General Baker Pasha, are now, so far as the works themselves are concerned, completely finished. Thanks to Baker Pasha's unremitting attention, the Ottoman capital is now placed beyond the reach of the Sultan's enemies. A highly competent British military authority, who has visited the works, pronounces them to be impregnable, and with that opinion the views of Tevfik Pasha and Akef Pasha are in accord. All that now remains to be done to render the work thoroughly complete, is to finish the road-making, and to construct the magazines.

—*Engineering.*

THE WORK OF THE SMITH IN THE SIXTEENTH, SEVENTEENTH AND EIGHTEENTH CENTURIES.*

By Mr. W. PENSTONE.

From "The Architect."

Among the manipulative arts connected with architecture that of the smith, I think, appeals as strongly as any to the æsthetic mind. There is a strong sense of individual power and skill impressed upon one by the contemplation of works of beauty and ingenuity developed from the rough ore, which awakens to its fullest extent the sympathetic interest forming so important a factor in the constitution of an "artistic" nature. The hand that wrought the interlacing scrolls and flowing leafage, centuries ago, has left its impress on the work so markedly that it seems through them stretched out to us in the universal brotherhood of art. I do not wish to compose a poetical exordium, but unquestionably there is poetry in the subject. From the days of Homer to those of Longfellow and Mackay bards have delighted to sing of the glowing forge and ringing anvil, and their music has furnished the *motif* to the great masters of harmony. Believing the sense of beauty in art to be in a great measure dependent upon extraneous associations and influences, rather than of a nature to be analyzed and scientifically deduced from inherent qualities contained in the subjects contemplated, I am unwilling, whilst looking at the productions forming the subject of our consideration, to eliminate entirely the element of sentiment in order to gain credit for a "highly practical" paper.

The metalwork of the Renaissance fully partakes of the incongruities, vagaries and debasements common in the contemporary architecture, so irritating to the modern mediævalists and purists, from whose platform it is easy to discover reasons why the greater part of the works of this class should not rank as high productions of art. But speaking generally as to the work of the period, much interest is awakened, and indeed many a lesson may be learned from these very vagaries, the outcome of an age when the increase of populations was leading to a spirit of restlessness and travel, and the struggles between old formulas and new ideas developed constant incongruities and piquancies in the vigorous life, which is so strongly reflected in the literature and art of these centuries. In the new motives and fresh impetus given to art workmanship at this time may be found ample field and principles for study and judicious imitation, without reproducing extravagances for the sake of quaintness or making precedent of failures.

It is worthy of remark that whereas in the earlier Gothic period the ironwork has a character of its own, consonant with but not in imitation of the other architectural details of the time, in its later developments the ornamental forms of wood and stonework were adopted by the smith, and wrought with wonduros skill and finish, but with a corresponding loss of power. The introduction of sheet-iron into use during the fourteenth century brought other tools into play than hammer and tongs; and although the new form of material was at first used, with the simple adaptiveness and propriety so characteristic of the mediæval workman, the greater ease of manipulation in time led to over-elaboration and imitation, in lieu of natural treatment of the material. At the end of the fifteenth century we find the work of the smith in locks, hinges, railings, etc., with all the detail characterizing the contemporary stonework. Traceries, crockets, finials and foliations are executed by means of overlaying plates in many thicknesses riveted together, chiselled, stamped and chased.

But the iron industry was now growing with great rapidity, and assuming a more important place than it had hitherto occupied. In the next century the Southern forests of Germany and our own timber districts were glowing with furnaces; and with the increased facilities for the production of the metal came increase of power in dealing with it as

* A paper read before the Architectural Association.

an ornamental material. In the hands of those artist workmen who, encouraged and protected by the municipal systems, added so much to the power and wealth of the great independent or semi-independent cities of central Europe, metallic design was developed with a vigor and freedom which left behind the architecture of the age, then in the efflorescent decadence of an exhausted style. And although this branch of work partook of the infusion of Classic detail with which, as with new blood, it was attempted to reinvigorate constructive design (and which did indeed give some sort of new life), it did so in a perfectly natural and adaptive manner.

For the best examples of the work of the sixteenth and seventeenth centuries we must turn to Germany, certainly for the most numerous. The great imperial city of Augsburg and its neighbors seem to have especially fostered the art of the smith. The hinges and other ironwork on the doors of the Townhall, a building erected at the commencement of the seventeenth century by Elias Holl, are good examples of the treatment of flat iron, cut into scroll interlacing patterns, lined and worked up with the chisel. There is a peculiar character about this class of German work. The curves seem to have been suggested by the tentacles of the star-fish. Work of similar character is to be found at the Dom Kirche, which also contains good railing. This latter, however, whilst showing a close grille of excellent design and a beautiful corona of flowing scrollwork, is spoiled by the extraordinary freak of representing at bottom a platform surrounded by balusters in perspective on the vertical plane. There are two or three railings of much beauty enclosing the chapels of the great Fugger family in the Cathedral of St. Ulrich, the moulded standards of which deserve attention. The railing enclosing the Augustus fountain is a very remarkable work, consisting of a much-enriched corona of scrollwork above moulded uprights. The cloisters of St. Anne's Church also contain good work. At the "Three Moors" hostelry in the same city, in the chamber shown as that of Antony Fugger, is an iron stove, dated 1532, ornamented with scenes from the wars of Maximilian I. Augsburg especially excelled in the use of the cold chisel and chasing. Besides sword and dagger handles treated in this manner, detached statuettes were carved out of the hard metal. Considering the much greater adaptability of other and mixed metals for this purpose, and the rapid oxidization to which iron is liable, one cannot but consider such labor as in a wrong direction. One of the most elaborate works of this description is now at Longford Castle, near Salisbury. It is a chair presented by the city of Augsburg to the Emperor Rudolph II., decorated with small statues and reliefs representing the history of the Roman Emperors, most highly wrought and chased. It is the work of Thomas Ruker, A.D. 1574.

It is of course entirely out of our province to take up the subject of arms and armor which at this period received the highest decorative skill of the smith, and such works as this may be relegated to the same class. I do not intend to make a catalogue of the chief works in iron, but merely to point out a few accessible examples which are worthy the attention of the student. At Salzburg (Austria), in the cemetery of St. Peter, are several grilles to tomb entrances of the seventeenth and eighteenth centuries. The best of these is that of the Zillber family, 1640, a good design with the prevalent round iron scrolls, flat leaves, and repousée masks. It is this period, that of the sixteenth and early part of the seventeenth centuries, which I consider furnishes the best examples of iron treatment, fully equal to, if not surpassing, any previous efforts of the smith in Germany, even at the best period of Gothic work. Most of the examples I have quoted belong to this era, and much work of the kind may be found scattered over Germany. Nuremburg, as might be expected, contains many specimens. One interesting piece is the railing around the Schoenbrunner fountain, the work of an Augsburg smith named Paul Koen. This encloses a fine structure of Pointed work, and the feeling in cuspings to cresting and buttressed standards is decidedly that of the Late Gothic. But the character of the foliage and scrolls to standards is of an independent type. The grille itself is of a pattern much used, cross diagonal bars forming diamond patterns, those in one direction

being placed square, and in the other edgewise, the former passing through the latter. Scattered upon this ground are sprays of foliage and geometrical patterns, entwining and interpenetrating the bars. Another example of similar work may be found in Vol. III. of the "A. A. Sketch Book," in a grille to a house at Frankfort, sketched by Mr. Aldridge; and on the same plate is a drawing of gates to a chapel at Cologne, which is suggestive in character, the lower part being filled in solid with wood and flat iron. The ancient Nuremburg houses contain many grilles. A fine one is that to No. 37 Winkler Strasse. There is a fountain enclosure of simpler character than the Schoenbrunner in the Ebner Strasse. Riveting in this work is rarely resorted to. In the flat iron the intersecting bars are halved and welded, and in the prevalent round bar work they pass through eyes in the opposing stalk. The branches are well welded on the larger ones, often uniting inside a cup terminating the main stem. The lines generally flow easily out of one another, spiral patterns predominating. The round smaller stalks flatten into sprays or small leaves, whilst the larger terminations are cut from the sheet in the form of leaves or foliated masks. These were often painted and gilt, or repoussé, and lined with the chisel. Quaint forms, recalling—perhaps representing—the gnomes and dwarfs with which Teutonic imagination people the depths of the forest and recesses of the mine, are very generally introduced, being boldly indicated by the chisel in the flattened iron. The work displays a suitable amount of finish, but the marks of the forge are not obliterated by the file.

The most noticeable feature of this Early German Renaissance work is the beautiful flower termination so generally used, and which I consider a triumph of just conventionalism. The petals, stem, calyx, leafage, and buds are represented in an illustrative and general rather than an imitative manner, a treatment more in accordance with true principles than the closer renderings of specific flowers, beautifully executed as they are, found in later work. These terminations severely test the powers of the modern smith in reproduction, being formed by intricate pieces not riveted or soldered but welded together from the furnace. Indeed, there are many operations of the old smiths which appear to have been lost, as, for instance, that by which the railings to the tomb of the Emperor Maximilian at Innsprück are formed. Here leafage undoubtedly of repoussé work has been applied to the baluster formed uprights in such a manner that it appears as if wrought in one piece. There is a very careful drawing by Mr. Anderson, in the last volume of the "Sketch Book," of one of the flowers I have been speaking of. Others will be found among smaller sketches on the walls. At Munich some good street work still remains. The church of Notre Dame formerly contained fine enclosures of early seventeenth century work, but during its restoration in 1860 these were taken out and probably destroyed, a fate that has, I fear, too often overtaken ecclesiastical work of this description during the earlier stages of the Gothic restoration movement. At Bremm, on the Moselle, there is, I believe, a curious iron pulpit, dated 1663, but I have not been able to find any illustration of it.

From the end of the sixteenth to the middle of the eighteenth century it was everywhere the custom in Germany to ornament tombs with iron crosses, though they have been very generally removed, in some instances being preserved in the vaults belonging to the burying-ground. They were generally painted in oil and part gilt, and have often a small locked box or reliquary at intersection. A good specimen of the general style may be seen in the South Kensington collection, in the form of a cruciform candelabrum, also some examples of cruciform lamp suspenders used in lighting churches. Cressets or torch holders, and other funeral furniture, in wroughht iron of the sixteenth and seventeenth centuries, have been often preserved in churches, and the Cathedral of Cologne possesses some remarkably fine examples. There is some good ironwork in the Cathedrals of Ulm and Ratisbon. The work of the period I have been dwelling on is characterized by a boldness and vigor which later became much refined upon.

The features and details of Classic art which in Italy were redeveloped with a refinement due to the presence of the ancient models and the character of the

people received at the hands of the northern smith in their earlier introduction a very free translation in which the element of what may be termed elegance was often entirely lost, whilst that of power was intensified. A remarkable exemplification of this spirit in art will doubtless be familiar to students of the great master of the German Renaissance, Albert Durer, whose sketches and adaptations from works of the Italian painters display a total indifference to their refinements and exaggerations of their most forcible points. In truth, until the seventeenth century, the influence of the revival was but little felt in German metalwork, the artists in which, taking a departure from the forms of the later Gothic, had formed in the previous century or so a school of their own, of great originality. But the Thirty Years' War, paralyzing the industries of Germany, seems to have stopped the full development of this national style, and that country never recovered her pre-eminence in this direction. The later work of the seventeenth and the eighteenth centuries succumbed entirely to the classic spirit everywhere triumphant, and, except for a somewhat sturdier rendering, there is little to characterize this from that of other countries. The execution is always good. Rich work of the heraldic "lambrequin" character was after compiled by various flat pieces overlaid and welded at the stem, but branched, twisted and curved in various directions as they develop.

In Italy, naturally, the return to classical traditions appears at a date anterior to the acceptance in other countries. Thus, in the well-known lantern and torch-holders affixed to the Strozzi Palace, these forms are adopted at a period when work of the Pointed style was being carried on everywhere. They are the work of Niccolo Grasso, about 1480. The warm climate of the South led to the extensive use of balconies and railings and open-work window panels, which may be found in great profusion in most of the Italian cities, especially Venice, mostly of the seventeenth and eighteenth century date. They are usually of scroll treatment in a combination of flat and round iron, with welded bands devoid of applied or cut leafwork, but of an infinite variety of patterns, re-entering curves being very generally used. Close diaper grilles with rosettes are, however, frequently met with. In the lighter forms what may be called "riband work" is much employed, the iron used being of the thickness of about one-eighth of an inch, doubling upon itself, and confined to the shape required by ties of thin metal. Beautiful chains of this description were used for hanging lamps, and are frequently picked up by the fortunate hunter in bric-á-brac. Stands for majolica bowls are another form in which much fine work was executed by the smith.

France possesses very good forged work, although it is not nearly as plentiful as in Germany. This may be in part owing to the excesses of the revolutionists, who, however, like our Ironsides, are doubtless credited with much more destructiveness than is their actual due. In the wholesale demolition of chateaux and desecration of churches such easily removable work, as iron gates and grilles, have doubtless disappeared to a large extent. Paris, however, contains many examples of fanlight openwork, chiefly of a late date. There are two of these of the end of the sixteenth century well worthy of remark. One is from a door to the church of St. Nicolas des Champs, semicircular in form, fixed in two halves in a wooden frame; fleurs-de-lys ornaments cover the points of contact of the bars, and rosette terminations are used, formed by many thicknesses of serrated sheet-iron. The initials S. N. and S. I. occur in the center. A fanlight somewhat similar is to be found in the Rue St. Paul. The Louvre contains a work of the smith which, like our Hampton Court screens, is monumental in character, and affords the best example of the industry in France at its best period. I refer to the two gates in the Apollo Gallery. Perhaps some of my hearers who may be well acquainted with French architectural literature can refer me to good illustrations of these. I have only discovered an engraving of one of them, which does not do it justice. These magnificent specimens were discovered in the reign of Louis Phillipe, at the Chateau de Maison Lafitte, in a sadly neglected state. They are of late sixteenth century date, and one is said to be the work of a Frenchman and one of

a German. They have been very carefully restored, the firm to whose hand they were entrusted having practiced their workmen for months on similar work before taking them in hand—a contrast to the treatment of our Hampton Court screens, which have been very indifferently repaired. The Louvre gates are of a purer Classical type than ours, and the details of construction are better. The structure of the design, however, is too directly imitative of wood paneling, and there is much repetition in the forms. They possess much grace of outline, and the top panel, representing amorini crowning Time, is a beautiful composition. At the Lycée Napoleon is a seventeenth century grille of good design in five panels, those at the bottom being well filled with a pattern of many parts; the center ones with open upright bars, and the top large panel occupied by a shield, surmounted by flaming scrolls. There are some balconies typical of the eighteenth century style at L'Ecole Central des Arts, formerly the ancient Hotel Salé. In the late seventeenth century the lines of design in iron follow very generally the contortions characterizing the school of decoration termed "rococo." The applied leafage is often of bronze. At Fontainebleau is a wrought-iron railing of seventeenth century workmanship surrounding the moat, and similar enclosures may be met with in a few of the chateaux remaining of this period. The cathedral at Rouen contains a railing of the reign of Louis XIII., enclosing the Chapel of St. Eustache. At Nancy, in the eighteenth century, Jean Lamour, smith in ordinary to Stanislaus, King of Potand, executed many remarkable works in iron which are among the cherished monuments of the ancient capital at Lorraine. They have, I believe, been illustrated in a special work. At Toulouse, in the Museum Garden, is a well with ironwork of the seventeenth century of somewhat eccentric design. A similar example of the same period may be found at Molhault, in Belgium, and there is one in the Hotel Cluny, at Paris. Window panels of similar character to the Italian ones we have mentioned, and altar rails of like design may be found in provincial towns, more especially in the southern provinces. We have here sketches of some from La Ferté Bernard and Nogent-le-Retun. The diligent explorer may find some of the old signbrackets remaining in Paris and other cities from which were displayed the trade marks or insignia once in universal use amongst tradesmen, but now displayed only by publicans and pawnbrokers. They were often of elaborate construction, like the example now at South Kensington. Also, though now very scarce, there are, I believe, to be found some of the old "lanterns" of decorative charater, from which were suspended the oil lamps used in street lighting, and which acquired so terrible a significance during the first Revolution. A most interesting and quaint work on iron was published in the year 1627 at La Flêche, by one Mathurin Jousse, a provincial working smith, who also issued treatises on perspective and carpentry. It contains a number of designs, chiefly for locks, keys, and similar work, which are marked by great spirit and invention. The original work is very scarce, but it has, I believe, been partially reproduced in fac-simile. The elaborate door furniture produced in Italy and France during the seventeenth and eighteenth centuries forms a subject in itself, and has, I believe, been so treated in a volume lately published in Paris. The knockers especially are of great variety and richness, containing often groups of figures executed in the highest style of art, such as the well-known one at the Palace Pisano, Venice, representing Neptune and sea-horses. These, however, belong more properly to the art of the sculptor and founder than to the art of the smith. Many examples are produced entirely by chisel and file, but the simpler varieties, such as two I have sketched at Candebec, will often afford good hints for the treatment of ordinary work. There is a fine knocker brought from Paris at Barnard's Inn, Holborn.

In this rapid sketch I can but just allude to the work in other countries. That in the Low Countries assimilates in character to the French, although perhaps heavier in style. At Forêt, near Brussels, in the Church of St. Denis, are good gates of date 1760. At Bruges may be seen some few wrought-iron finials to its many gables; note one in the Rue du Fil, dated 1628. Spain pos-

sesses much remarkable work in iron characterized by the ornateness displayed by its architecture. In Switzerland also fine work may be found in window grilles.

As I have remarked about the German, so in the work of Italy, France, Spain, England and the Low Countries, the national distinctions in style are but faintly marked from the seventeenth century. Scrolls, masks, acanthus and other leafage, urns, spears, swords and shields and other forms, all modelled on distinctly classic precedent, are used in a similar manner in all countries to produce works of great richness and beauty, but which often convey a sense of over-elaboration and artificial effects unsuitable to the material. In Germany, as we have noticed, the rendering of this classic detail is vigorous rather than elegant. In France, the facile and versatile spirit of the nation is displayed by graceful combinations of curvative and easy adaptations from antique models. In Holland there is often an affected quaintness, whilst in our own country there is to be found a certain sense of fitness and a degree of independence which makes much of our work most valuable and suggestive. These differences are of so subtle a nature that it would require a much more exhaustive paper to analyze them, and we must remember that the interchange of work and workmen among the different nations tended much to obliterate local characteristics.

I must now proceed to the home view of our subject. The metalwork of our Perpendicular period is of a very high class, though the forms are of marked architectural character. The enclosure to Henry VII.'s tomb at Westminster (in bronze or laten) is perhaps the finest example of such work to be found, and the railings to Edward IV.'s tomb at St. George's, Windsor, is a marvel of elaborate construction. Both of these are probably the work of foreigners, the latter being popularly ascribed to the hand of Quentin Matsys. I have not been able to discover any conspicuous examples of ironwork of the Elizabethan age, though much of the smaller work in lock-plates, hinges, etc., remain. In Exeter Cathedral there is a door-plate in the form of a crown of sixteenth century date, and the city itself possesses an interesting relic, probably of early seventeenth century workmanship, in some mace-holders of cut and chiselled sheet-iron colored red and green and parcel gilt. The vestry door to St. Saviour's, Southwark, has a handle in the form of a ring with lizards on it of the same date. At Hurst Church, in Berkshire, there is a curious wrought-iron bracket for hour-glass, dated 1636, painted and gilt. In most of the old Elizabethan mansions much useful work in the form of door furniture, though generally of a plain character, may be found; Eastbury House, near Barking, furnishes good examples. The Ashmolean Museum at Oxford has a fine lock-plate of a more ornamental description. I have here some sketches of a work of the Jacobean age, which is a very good example of the powers of the English smith. It is a screen formerly separating the pew of the Leversedge family from the Lady Chapel in the Church of St. John, Frome. I consider this specimen singularly happy in design, and delicate in execution. The composition gives due importance to the central feature bearing the armorial shield, whilst the side panels are agreeably diversified. The general size of main bars is $\frac{1}{2}''$ by $\frac{1}{2}''$ or $\frac{3}{8}''$. The lines of hammered work are not obliterated by sheet work, although there is quite sufficient of the latter to give a richness to the design. Altogether there is what may be called a restrained freedom about the piece of work which is pleasing. It has recently been added to the valuable collection of ironwork at South Kensington. Later, in the seventeenth century, we come to a series of examples which are probably well known to all London students—the screens from Hampton Court. They are twelve in number, and were formerly placed at intervals of 50 yards in the fence dividing the Palace home park from the gardens. They were, however, dropping into decay, and removed into the Palace to preserve them. Seven have for some years been placed on loan in the South Kensington Museum, and some have recently been placed in the building at Bethnal Green. Huntingdon Shaw, blacksmith, of Nottingham, is recorded as the artificer who constructed them, about 1695. His monument may be seen in Hampton churchyard. They are of large dimen-

sions (about 13 feet in width by 11 feet high), and altogether exhibit a surprising amount of labor and ingenuity. The general construction of the whole series is in one pattern, but four are of richer detail than the others. Panels 2 feet 4 inches in width, formed of uprights 2 inches square, filled in with a pattern of 1-inch bars, and strengthened by stays, form the supporting standards on either side. Between these is a flowing composition of elliptic scrollwork, with bold appliqué foliage and flowers surrounding a panel about 3 feet square, which in the four principal screens enclose representations of the natural emblems—rose, thistle, and harp—the remainder being filled in with a diaper pattern. Above this is a heavy swag or chain of flowers pendent from the beaks of eagle-headed scroll terminations, and crowning the whole is a foliated mask with a figured and tasseled apron. The detail is wonderfully wrought out, the small rosebuds and sprays being represented with great fidelity to Nature, as if in emulation of the work of Grinling Gibbons in wood. A naturalistic treatment, however suitable for the material in which the latter artist chiefly worked, is not, I think, at all so for iron. The ornament is almost entirely of an appliqué character; the larger scroll ends, a subject on which I shall say a few words presently, are even cased with sheetwork. It is very surprising that, notwithstanding the care displayed in the formation of the details, the whole is very badly put together, and it is no wonder that the influences of time and weather were speedily bringing these fine works of art to ruin. Few of the scrolls or stems are welded at their junctions, but simply united by iron tongues and pins, the heavy strains on which have in some instances caused them to give way. The leafage also, which in the most ordinary gatework of this period was always welded to the stems from which they spring, are merely riveted or screwed, the larger branches in several pieces. Notwithstanding such defects, however, their works must always be objects of admiration from the boldness and orignality of their design, and the evidence of patient skill in their production. There are other productions of the smith at Hampton Court Palace well worthy of attention, such as the balustrading of the King's and Queen's staircases, the work of a Frenchman, though doubtless from designs by Wren, of great importance; and familiar to most of you is the ironwork in St. Paul's Cathedral, by the same artificer as that last mentioned—one Tijou, a Protestant refugee. The hand of the master-designer is here very apparent, although probably very much more was left to the workman than would be the case under our present system. The gates to the choir are noble in design and proportion, and exhibit a refinement, compared to the Hampton screens, which may be partially due to the nationality of the producer. In those facing the nave, exception may be taken to the imitation of fluted pilasters in open work, and to the flattened flaming urns at the top. I do not think the urn-shaped standard terminations at all an inappropriate form, but I do consider them unpleasant if in the flat, especially if the smith attempts to put them in perspective, and more especially when he represents them as if seen from the clouds, as in the Leversedge screen. The side gates display neither of these defects, the paneling being filled with close scrollwork, and the corona containing sconces for large candles, twenty-three to each screen. Nevertheless, we lose the vertical treatment in the gates, which gives so much more value to the flowing work above in the others. The grilles at the back of stalls, the balustrade to gallery round the dome, and the work to the geometrical staircase are, especially the latter, worthy of study.

Many of the entrances to parks, public buildings, and mansions of the reigns of Queen Anne and the early Georges display noticeable gatework on a large scale. A list of these, if made, would be of some length, but useful to the student. Amongst the more remarkable we may mention the gates to the Clarendon Press at Oxford, 1712; those at Trinity and New Colleges, in the same city; the gates to Temple Gardens, 1730; and to Gray's Inn, 1723. In the older suburbs of London, and in many provincial towns, one's attention is often drawn to the homelike dwellings of the last century, with forecourts enclosed by wrought-iron railings and gates. Chelsea, Hampstead and Clapham contain many examples, and through the medium of the Association's

"Sketch Book" I have been able to place many illustrations upon the walls.

It is amongst this dometic work, rather than in the more ambitious efforts of the smith, that the student of design will find most valuable motives and ideas. There is always a sense of fitness for the purpose designed, and generally a temperate use of ornament other than constructional—that is, the hammered bars and scrolls are not overlaid with sheet-work, but depend upon the variety of curve and patterns into which they are wrought for richness. The natural structural composition of an open enclosure—that of upright bars—is seldom lost sight of, the leading lines being vertical, and the scrollwork being kept in subsidiary panels, or confined to the heads and principal standards. The gates themselves are often quite plain, the ornament being confined to the frame surrounding them. The flowing work, of beautiful design, gains much in value by being thus temperately employed, and the whole composition embellishes the building of which it forms a feature without disturbing its repose. Often unpretending enough, such work impresses one as that of men who gave their hearts to it, though it was usually produced in humble smithies. The careful and often excellent work turned out from our modern art factories somehow seems to lack the power of interesting you in its producer as this old work does. Doubtless one reason is that it is too perfect; you never see a curve gone slightly wrong, and the leaves are cut too closely to pattern, and are too well balanced. You can picture the old smith pausing to consider which way the curve should now be turned, or what twist to give the spray of leaf—possibly arguing a point of broken flexure with the idling critic, or interrupting his work to shoe a passing traveler's horse, and hear all the latest news of Marlborough's wars the while. One's mind would scarcely dwell upon the art-metal workman of the present day, tracing down on the sheet careful details of elaborate foliations. Before the opening up of the Northern and Midland coalfields, smelting operations were carried on in such forest districts as still afforded abundance of timber. In the reign of Elizabeth it was foreseen that the great demand for fuel to feed the increasing number of furnaces would tend to the rapid exhaustion of growing wood. Various repressive statutes were enacted, prohibiting the establishment of works altogether in some districts, and limiting them in others. The Weald of Sussex and portions of the neighboring counties were the nearest sources of supply to the metropolis. The earliest specimens of castings came from this district, and the "Sussex iron," in the form of andirons or firedogs and firebacks, is well known to the collector and dealer in "antiques." The decorative work in the firebacks is especially noticeable in the seventeenth and eighteenth centuries, some very elaborate compositions being produced, but always marked by a suitable or plastic treatment. The fine railings around St. Paul's, now being refixed, were the produce of a foundry at Lamberhurst in Kent, and are good specimens of the right treatment of cast-iron railings. The Sussex furnaces were finally extinguished in the middle of last century. Their history is an interesting one, and may be found in the volumes of the "Sussex Archæological Journal."

I have not the space to go into the question of cast iron, to the abuse of which useful manufacture we owe the pretentious, vulgar, and uncomfortable accessories which have disfigured our architecture to so great an extent.

The subject of iron design in the present day has been taken up by abler hands than mine. I only feel it incumbent on me to urge the necessity of making one's self thoroughly acquainted with the different phases it has gone through in the periods I have been dwelling upon. In the earlier German and the simpler forms of our own eighteenth century work, we have models of a natural and therefore artistic treatment of material which will repay close study, and I am sure each of these periods might be advantageously treated of in a more detailed and technical paper than I have been able to put before you. I have now only time to indicate one or two points wherein I think such work offers useful guidance to the designer.

The most natural way of employing iron in an independent manner is surely that of an arrangement of bars or lines, connected together in a constructive manner to combine lightness and

strength. These bars may be manipulated in various ways, of section round or square or moulded, and the combinations of curved and straight lines offer an endless variety of pattern. Decorative work of lighter form, in which the sheet-iron is brought into play, may be applied to a certain extent only without interfering with the sense of stability given by the preponderating forged work. And this is always the principle of the earlier smiths, though generally lost sight of in the more important works of the later centuries, when the forged work was often but a constructive frame concealed by the application of decorative forms. Large mouldings imitative of those in stone and wood, were formed out of sheet-iron, enclosing the bars supporting the structure, whilst cut and beaten work, highly wrought and made-up imitations of natural foliage, human forms, draperies, and other objects, frequently attached by rivets only, crowded the whole composition. Now, in the German work the figures which were often introduced were usually continuations of the scroll bar, out of which they were worked in the solid, forming part of the structural composition, though often with wings and foliations of sheetwork attached. The leafage grows naturally out of the main lines, to which it is kept in subordination. The terminations of the voluted scrolls are points of the design which fitly receive ornamentation, and this detail alone is deserving of attentive study. Although the use of appliqué sheetwork in the form of flowers or geometrical rosettes is here quite a legitimate form of enrichmeut, we find that very generally sufficient effect is produced by simple treatments of the hammered bar. A great variety of these may be evolved out of the two principles of spreading the end—in one case in the direction of the depth of the bar, in the other in the direction of its width. These methods in their simplest form, with a parallel treatment and a variation of round and flat iron, are generally found used together in our English gatework, giving a diversity to otherwise similar forms. By welding on additional metal, and by a combination of the two principles, with alterations to the sectional form of bar, many other developments may be obtained of which we have here one or two examples, chiefly German. Or the termination may be hammered and chiselled, or stamped (as usual in modern work) into dog-heads or geometrical patterns. In all cases where exposed to probable rough treatment, these methods are preferable to the use of cut and beaten ornament. As an example of consideration of fitness for purpose, I would point to a gate of German work now at South Kensington.

It is of a close diaper pattern, a fleur-de-lys ornament being formed on the upright bar by a stout hammered foliations welded on. The points, of which there are many, are all carefully turned inwards, and protected by the enclosing barwork. Rounded clips are used, and it is quite possible to lean or be pushed against the gate without risking tatters—a desideratum which is too frequently lost sight of by the modern designer. As a general rule, I do not think ordinary protective enclosures require highly ornamental display. The area railings of the last century, which are familiar to us all, with their standard panels at intervals in the assemblage of square bars, are to my mind much more satisfactory in a long frontage than elaborate patterns. The bold forms of the spear-heads and occasional scroll ramps, with the now obsolete lamp-brackets and torch extinguishers, quite sufficiently relieve the designs from tameness—a failing which this material suffers less than any other, and which is often most conspicuous in the most ornate work. There is often more character in a simple forging than in many pretentious patterns drawn from the sand-mold, as a comparison between the spear-heads I have mentioned and the usual run of cast railing will testify. And I would repeat again that the great lesson which all old work impresses upon one is, that the refinements of the file, scissors, and pliers, should not be allowed to emasculate the vigor produced by hammer, tongs, and chisel. In what I feel to be rather too sketchy a paper, my endeavor has been to interest the architectural student in a subject worthy of careful attention—the present phase of the erratic course by which modern art progresses has brought the periods I have been referring to to the front. Whether

it is a passing "craze," as some would have, and we are to return to the earlier work, or whether, having run through the styles of all centuries from the twelfth to the eighteenth, "to get our hands in," we shall now satisfactorily develop a nineteenth century school of distinct character, is a question I should not care to discuss. But of this I am sure, that all earnest, laborious work, of whatever age or style, is worthy of study, and the lesson of thoroughness may well be learned in these productions of the forge.

"The smith also sitting by the anvil and considering the ironwork, the vapor of the fire wasteth his flesh, and he fighteth with the heat of the furnace. The noise of the hammer and the anvil is ever in his ears, and his eyes look still upon the pattern of the thing that he maketh. He setteth his mind to finish his work, and watcheth to complete it perfectly."

THE MODERN HISTORY OF GUNPOWDER.

From "Journal of the Society of Arts."

We can modify the rapidity of ignition of powder, first, by varying the size and form of the grains or individual masses; secondly, by varying the density or compactness of the powder; and thirdly, by variations in the finish, or the nature of the surfaces of the grains or masses. These are the three most important means which have, up to the present time, been used, and with success, for producing the necessary modifications in the action of fired gunpowder. I will just show you the difference in the rapidity of combustion of gunpowders of similar composition but of different sizes. Here we have fine grain or small-arm powder; here is the old cannon powder used in small bore guns, and for a short time in the earliest Armstrong guns; and here is a large grain powder, subsequently manufactured for rifled guns. This large grain powder was, at the time of its introduction, regarded as a great advance in the modification of the rapidity of burning of powder; but within a short time it became evident that this powder was too violent in the heavier of the charges which had to be used. The next step was to produce a powder of much larger size, and of uniform shape and size, by powerfully compressing meal powder into small cylindrical molds, and thus obtaining pellets of powder about $\frac{3}{4}$ inch in diameter, and $\frac{3}{4}$ inch in height, the inflaming surfaces of which were increased by partially perforating them. This was the first very large powder which was introduced in England for heavy guns, but a very large grain powder had just previously been introduced in America, under the name of "mammoth" powder, and a much larger powder, of prismatic shape, also of American origin, was adopted about the same time in Russia and Prussia. Soon after the adoption of pellet powder, in order to facilitate manufacture, a powder of similar dimensions to the pellet, but of irregular size, was produced by us, not by molding meal powder into distinct masses of uniform size, but by compressing it into thick cakes, and then breaking these up into pieces of a particular average size, which were afterwards deprived of sharp edges and angles and well glazed. The name of "pebble" was given to this powder. The average size of the pebbles is about $\frac{3}{8}$ in. by $\frac{1}{2}$ in., and one of them has about the same weight as 110 particles or grains of the rifle large-grain powder which I just now showed you. I will now compare the burning of these discriptions of powder, and you will notice the great difference which the size of the individual particles makes in the rapidity of explosion, even when the powder is fired in the open air.

These powders are all similar in their composition, and not very greatly different in density; but the modification of the density and compactness of powder, as I have said before, constitutes a very important auxiliary means of modifying the rapidity of action of fired gunpowder.

Although the pebble powder was found

to furnish far more satisfactory results than the rifle large-grain powder, or even than the pellet powder which just preceded its introduction into our service, it occasionally exhibited a serious want of uniformity in the pressure which it exercised in the gun, especially when it came to be employed in the so-called "Woolwich Infants"—the 35 and 38-ton guns which until quite recently were the heaviest guns in our service; projectiles weighing from 700 lbs. to 800 lbs. being fired from them, with charges of 120 lbs. to 160 lbs. of powder. Occasionally, even in smaller guns than these, some exceptionally severe pressures were found to be exercised by this powder in some parts of the gun. The cause of these occasionally unfavorable results were very carefully investigated by the committee entrusted with this work. In some cases they were traced to an exceptional irregularity in the size and shape and density of the individual masses of powder, but they were also found to be connected with other conditions which occur in the firing of heavy charges in guns, and which I regret that time prevents me from discussing in detail. I must content myself with just referring to one of these disturbing causes.

As long as we had only a small cartridge to ignite, it mattered little where we ignited it, whether at the top or at end furthest from the shot, the ignition took place throughout with comparative uniformity. But as soon as the cartridges were considerably increased in size, and the column of powder became a comparatively long one, it made a considerable difference where the cartridge was ignited, especially when we came to deal with a comparatively slow burning powder. If the cartridge was ignited at the rear, the gases produced by the first ignition, rushing with great velocity towards the shot, would be checked in their career by the inertia which it opposed to them, and thus, before the whole charge was ignited, irregular and locally violent pressures, so-called wave-pressures, would be produced in the bore of the gun. This action was in the first instance diminished, if not quite got over, by the simple expedient of placing the vent of the gun in a position towards the centre of the charge, so that the flame produced by the first ignition could spread more rapidly through the different parts of the charge. But when we came to use such enormous charges as those of our latest guns—the 80 and 100-ton guns—charges of from four to five hundred pounds, contained in cartridges 60 inches and upwards in length, then special expedients had to be tried, with the view of lighting up the powder uniformly, or of causing the flame to spread quickly to all parts of the cartridge. The most successful of these expedients was to ignite the cartridge by a small charge of powder placed at the end of a species of conical open cage, which reached from the rear end of the cartridge up to about the center. By this arrangement, which you here see represented (diagram), the fire from the vent is very quickly conveyed to the center of the charge, and communicates through the open cage to the different parts of the cartridge.

I must still refer to another expedient, the result of careful reasoning and systematic experiment, which has been adopted with great advantage in regulating and equalizing the pressures developed by the ignition of large charges of powder. This consists in so making up the cartridge that it shall not completely fill the space which it occupies in the gun, so that an air space is provided at the seat of the charge, into which the gases first developed from the powder expand, whereby the pressure at the commencement of the explosion, or the initial pressure, as it is termed, is relieved, and the accumulation of pressure consequently takes place more gradually. For if the pressure in the powder-chamber of the gun is comparatively low at starting, the further burning of the powder will take place more gradually, and the pressure will increase more uniformly than if a comparatively high pressure be at once produced, in consequence of the very small space which the gases are compelled to occupy at first, or of the powder presenting a very large inflaming surface, or of its surface being very rapidly inflammable. In providing the air space, of which I have endeavored to make clear to you the advantage, the most convenient mode of proceeding is to make up the cartridge so much smaller in diameter than the bore or powder-chamber of the gun as is necessary for

affording the desired total space in which it is desired to inflame the charge, the length of the latter being of course proportionately increased. The space might also be provided by leaving an interval between the cartridge and the base of the shot; but from what little I have said regarding the occasional production of severe local pressures in the gun, and from what many of you may have read in the public prints with regard to one possible explanation of the recent fearful calamity on board the *Thunderer*, you will be prepared to hear me say that it is only possible to have reccurse to this mode of providing air space for the charge to a limited extent, without risk of submitting the gun to the distressing and possibly destructive action of a very sudden and violent local strain near the seat of the shot. For if a considerable interval exists between the charge and the projectile, the products of explosion rapidly generated from the powder will rush into this air space with so high a velocity that, upon being suddenly brought up by the projectile, which is still stationary, or has only commenced to move, they will strike a blow of enormous force upon the latter, and upon the part of the gun's bore immediately in rear of it. Remember, I am not speaking of this as the cause to which the bursting of the 38-ton gun on board the *Thunderer* is to be ascribed,* either wholly or in part, as all the circumstances attending that terrible accident are not yet thoroughly known to us, and perhaps never may be, sufficiently to throw proper light on the calamity. I only desire to point out that, in applying the expedient of air spaces for relieving the pressure developed upon the ignition of very large charges in guns, such an application might actually be productive of mischievous instead of beneficial results, if proper thought were not given to all points connected with the action of fired gunpowder in a confined space.

Before leaving the subject of the improvements recently effected in the ignition and the mode of burning of large charges of powder in guns, I must briefly refer to a simple device which has been successfully elaborated with decidedly beneficial results, its effect being, on the one hand, to utilize more thoroughly the projectile effect of the force of exploding gunpowder, and, on the other hand, to protect the bore of the gun, especially that part situated immediately over the shot, from a kind of injury—sometimes by no means inconsiderable—caused by the enormously rapid rush of gas through the small space existing between the shot and the bore. The scoring, or so-called erosion, of the surface of the gun—due to the tearing away and pushing one over the other of the metal particles by the torrent of highly-heated powder products rushing through the very narrow space—has sometimes been so considerable as not simply to affect the accuracy of fire of the gun, but also to develop cavities in the metal, especially in the direction of the rifling, which might in time become serious sources of weakness.

This peculiarly-shaped disc of copper is one of the most efficient forms of so-called gas checks, which have been devised to protect guns from this kind of injury. When a disc of this kind is fixed to the base of the projectile, the first effect of the exploding charge is to bring the flange or broad rim of the disc into close contact all round with the surface of the gun, including that of the rifling, and thus effectually to prevent escape of gas past the shot, so that the scoring action is guarded against, while, at the same time, the force of the exploding powder is more thoroughly utilized.

And now, having endeavored to give you some idea of the means employed, as the results of patient systematic investigation, for regulating and at the same time utilizing more completely than formerly could be done, the explosive force of gunpowder when used in large charges, and in the form of the large fragments which I have described under the name of pebble powder, I have only to add a few words to this very long story, for the purpose of making you acquainted with the very latest modifications which gunpowder has undergone.

In order to test still further the effect of increase of the size of the masses upon the regularity of burning, and the maximum and mean pressures developed by very large charges, experiments were made in the Woolwich Infants, with gunpowder of considerably larger size than

* The lecture was delivered before the publication of the Report of the Committee.—Ed. *S. A. Journal.*

pebble powder, and the most satisfactory results, generally, were furnished by a dense powder, in the form of roughly-shaped cubes, with rounded edges about 1½ in. in diameter. This powder, which is produced like the smaller pebble by breaking up large cakes of compressed powder of proper thickness into masses of the required size (but naturally of somewhat variable dimensions) now constitute the service powder for our largest guns. It is of this powder that charges of from 400 lbs. to 425 lbs. are fired in our 80-ton guns, for the purpose of propelling shot 1,750 lbs. in weight.

But, although good results are furnished by this powder, we are not content to rest in our labors, but are aiming at further desirable improvements. Experiments have been made by us with even larger powders than our 1½-inch pebble, and it is not impossible that we may even come to build up our gigantic cartridges for the 80 and 100-ton guns of large slabs, of the full diameter of the cartridge; or there may be other directions in which we may be led to work, with prospects of fruitful results, than that of the variation of inflaming surface and density, with the object of increasing the power, while not interfering with the longevity, of our large guns.

And here I should state that while we have been active in the improvement of gunpowder, the Italians, who have been most intelligent artillerists from early days, and have of late devoted a large amount of scientific acumen as well as considerable resources to the development of the power of guns, have not been standing still in the matter of gunpowder. In fact they have been stealing a march upon us, for they have produced a powder—a modified form of our largest powder—which gives even better results than those we have as yet been able to obtain in our largest guns. By means of a new system of building up their masses of powder, they appear to have been very successful in attaining with it, in the first instance, comparatively slow action, followed up by a quick action of the charge, and a subsequent uniform sustainment of moderate pressure. In a recent trial, whereas 463 lbs. of our large powder gave, with a 2,000-lb. shot, in the 100-ton gun, a velocity of about 1,600 feet, with a pressure of about 21 tons on the square inch, the Italians were able to use 110 lbs. more of their new powder with the same weight of shot, imparting to the shot 100 feet more velocity than obtained with our powder, while the mean pressure in the gun was three tons per square inch below that which our powder developed.

Results a little superior to the best which have been furnished with the 80-ton gun by our large powder have, moreover, been recently obtained by us in a trial which we have made of the latest form used by the Germans, the prismatic powder to which I have already referred. If any incentive were required for continued exertions on our part for the improvement of gunpowder, it would be furnished by these evidences of the intelligent activity of, and of successes achieved in the same direction by, artillerists of other countries.

LIGHTHOUSE ENGINEERING.

From "The Engineer."

THE foundation stone of the new Eddystone Lighthouse was laid June 21, by the Duke of Edinburgh, in presence of the Prince of Wales. The progress which has been made in lighthouse engineering since the first stone of the existing lighthouse was laid has not been small; and yet it is not quite so apparent as might be supposed. Let us see in what it consists. Let us compare the practice of lighthouse engineering in the present day with its condition in the days of its great professor, John Smeaton. As regards the form given to such structures very little advance has been made on Smeaton's famous design, for the sufficient reason that very little advance was possible. The contour of the new "Eddystone" will not essentially differ from its predecessor, though its

dimensions will considerably exceed those of Smeaton's column. Its engineer—Mr. John N. Douglass—has described the proposed building as "a concave elliptic frustrum, the generating curve of which has a semi-transverse axis of 178 feet, and a semi-conjugate axis of 37 feet." Nor is there any important difference in the material now used in the fabric of rock lighthouses from that which was employed by Smeaton, excepting that whereas the first rock tower was constructed externally of granite, with internal blocks of Portland stone, its successors are usually composed entirely of the former, of a superior quality to the "moorstone" which Smeaton procured from the quarries of Lanlivery. Stone has, indeed, been used in most of the rock lighthouses that have been recently erected. The last attempt in this country to construct a rock tower of any other material was that memorable in connection with the Bishop Rock, off the Scilly Islands. The first lighthouse designed for this site, in 1848, was of iron; but, when the building had been raised to the necessary height for receiving the lantern, it was completely swept away by the sea. It is said that the executive engineer of this lighthouse, and of the present noble tower which was commenced immediately after the above-named catastrophe, regarded with perfect complacency the unsuccessful termination of his zealous endeavours to raise the iron edifice. He had never concealed his dislike for the type of structure with the erection of which he had been entrusted, and probably now felt that it was better, both on grounds of economy and humanity, that the house should be demolished at this stage of its existence, than, like Winstanley's famous building, when completed and inhabited.

In reference to the general dimensions and internal method of construction of Smeaton's tower, compared with modern rock lighthouses, a brief description, in these respects, of the present and proposed Eddystone will sufficiently indicate their essential points of difference. Smeaton's lighthouse has its base 32 feet in diameter, and the focal plane of its light 72 feet above high-water, with an illuminated range of fourteen nautical miles. It has four rooms, 12¼ feet in diameter, in addition to the lantern, and contains about 13,343 cubic feet of stone. The new lighthouse will have its base 44 feet in diameter, and the focal plane of its light 130 feet above high-water, with an illuminated range of seventeen and a half nautical miles. It will have nine rooms, the seven uppermost being 14 feet in diameter, in addition to the lantern, and will contain about 69,100 cubic feet of granite. In Smeaton's tower there are 636 stone joggles, 1800 oak trenails, 4,570 pairs of oak wedges, eight circular floor chains, and 226 iron cramps. In modern rock towers scarcely any such appliances are now used, though composition metal bolts, slit and wedged at both ends, are employed in fastening down the foundation courses. The present system of dovetailing the stones one into the other is indeed, so complete, and the modern quick-setting cements possess such an advantage for hydraulic work over the mixture of blue lias and terra-puzzulano limes used for the blocks of Smeaton's lighthouse, that, excepting where the courses come in contact with the rock, no necessity exists for separate joggling and trenailing. Smeaton's method of bonding was, like every other mechanical arrangement which his skillful mind devised or adapted, characterised by extreme ingenuity, and was the first successful application to masonry of a process which had previously been almost exclusively confined to carpentry. In his writings—to which Robert Stephenson always referred young engineers when they asked him what they should read—Smeaton relates minutely, as is his wont, the development of his mode of dovetailing, from the first hints he received by observing the manner in which the kerbs along the London footpaths were fixed, to the elaborate system which he eventually "maturated," as he calls it, and applied to the Eddystone Lighthouse. It is therefore, only necessary that we should here notice the latest and best example of that system. This is the invention of Mr. Nicholas Douglass, and has thus been explained by the present engineer to the Trinity House:—"It consists in having a raised dovetailed band, 3 in. in height on the top bed and one end joint of each stone. A corresponding dovetailed recess is cut in the bottom bed and end joint of the adjoining stones, with just sufficient clearance for the

raised band to enter it freely in setting. The work, when thus put together, and set in Portland cement is nearly as homogeneous as solid granite."

But, leaving this branch of the subject, and coming next to the consideration of the mode of carrying on the operations at sea, the wonderful growth of mechanical science during the present century confers, of course, immense advantages for the prosecution of these labors over those which Smeaton enjoyed. Foremost among such is the facility with which the transport of material from the workyard to the rock, and the landing and depositing of it thereat, are effected by steam power. The material of Smeaton's tower had to be conveyed from Milbay to the Eddystone in sailing craft, which were often hindered by adverse winds, or none at all, and thus sometimes occupied days in reaching the rock; and the work of discharging and placing in position their cargoes was a slow and laborious task with the crude gear then available for such purposes. The vessel now employed in conveying from Oreston to the Eddystone the material for the new structure is a twin-screw steamer, capable of carrying 120 tons, and of performing the passage in a little over an hour. She is fitted with a pair of double barrel steam winches, by which the stones for the lighthouse will be hoisted on board, hoisted again to the deck, and thence to the rock, besides pumping out the water from the foundations at each tide. Another steam winch fixed on the tower will hoist the stones into position. The rock drill is also now proving a useful instrument for the excavation of the foundations of rock lighthouses. One of the best of these tools will do as much boring in an hour as was executed by ten of Smeaton's Cornish "tinners" with their jumpers. Nothing can demonstrate more forcibly the celerity with which the rock operations in connection with the building of sea lighthouses are now carried on, than a statement of the actual time that the men were employed on the rock in raising his tower, and the time now required for raising even a larger structure. The total number of hours worked on the rock in the erection of Smeaton's lighthouse, which contains, as already stated, 13,343 cubic feet of stone, was 2674. The total number of hours worked on the rock in the erection of the Wolf lighthouse—lighted in Jannary, 1870—which contains 59,070 cubic feet of stone, was 1810. In other words, the landing and building operations of a rock lighthouse, which now occupy an hour, would have occupied an engineer in Smeaton's day six hours thirty-two minutes. But the most important development of which we have to speak, in connection with our subject, is that which relates to the optical branch of lighthouse engineering. And, first, let us deal with the lantern as an essential element in reference thereto. Smeaton's lantern was of the square type, having massive horizontal and vertical sash bars, which obstructed, in certain directions, nearly 50 per cent. of the light from the lamps. This type of lantern has not long become obsolete in our lighthouse service, and until quite recently was the only one used in the lighthouse service of the United States. It was, however, a source of infinite mischief; for not unfrequently one of its vertical sashes, interposing between the light and the point of observation, proved so complete a barrier that mariners have reported a light extinguished altogether, when it was merely thus practically extinguished to them. The late Mr. Allan Stevenson and Mr. James Walker, by adopting inclined framing and otherwise, greatly improved this old form of lantern, and in 1864 the present engineer to the Trinity House invented his cylindrical helically framed lantern, now solely used for new English lighthouses, which besides being optically perfect in form, and posessing a maximum of strength, offers a minimum of obstruction to the light sent from the illuminating apparatus.

In fact, such shadow as the framing of this lantern casts was reported by Faraday to be entirely lost at a distance of less than 100ft. And now in the last place, we come to the light itself. Smeaton's tower was illuminated by twenty-four tallow candles—five weighing 2 lbs.—which combined were equivalent to 67 standard sperm candles of the present day. They were hoisted on a chandelier without any optical arrangement for directing their beams to the sea.

Consequently a large proportion of even their feeble power was lost to the mariner. In 1810 twenty-four argand lamps and reflectors were substituted for

the candles. Thirty-five years later an optical apparatus, on the dioptric system of Augustin Fresnel, took the place of the argand burners; and in 1872 the 4-wick Trinity House lamp was substituted for the one of three wicks previously used, the net result of this series of improvemnnts being to augment the light, when sent to the mariner, from 67 to 73.25, standard candles.

We understand the corporation of Trinity House have not yet decided on the character of the dioptric apparatus for the new Eddystone; but, as it is it will doubtless be of the first order, whereas the present apparatus is, for want of area in the lantern, only of the second order, will embody all the most modern improvements in opticial pharology; and will probably be one of the group-flashing class of apparatus, which the Trinity House is now extensively adopting, both because of their accumulative properties, and their eminently distinctive character. Its light may be expected to considerably surpass in brilliancy and effectiveness the splendid beam which now issues, but will soon cease to shine, from Smeaton's noble tower.

A NEW THEORY OF TERRESTRIAL MAGNETISM.

By Profs. PERRY AND AYRTON.

From "The Journal of Science."

At the meeting of the Physical Society, in April, Mr. Ayrton explained, on behalf of Prof. Perry and himself, a theory of terrestrial magnetism which has the great novelty that it makes the existence of the earth's magnetism depend solely on the earth's daily rotation, and does not require, as do all other theories based on electro-magnetic phenomena, the existence of other bodies in the universe. In fact, they have arrived at the result that if any body of any material has a static electric charge, and if it rotates about an axis, then *per se* there will be a magnetic field in the interior of this body as well as in the neighborhood outside.

In 1876 Mr. Rowland, working in Professor Helmholtz's laboratory, proved experimentally that a quantity of electricity in mechanical motion acted like an electric current in deflecting a magnet; and it is on this result that Profs. Perry and Ayrton have based their whole theory. For they point out that since points near the surface of the earth have different linear velocities from those in the interior (although all the points have the same angular velocity of rotation round the earth's axis), it follows that if the earth had an initial electrical charge, residing, of course—in accordance with the well-known electrical law—on its surface, the electrified particles would have velocities relative to the remainder; hence, as a direct consequence of the results of the experiments published by Professor Helmholtz, the interior of the earth would be a magnetic field, quite independently of its interior constitution, and precisely similar reasoning, of course, proves that outside of the earth's surface there would also be a magnetic field.

In order to solve the difficult problem of determining the electro-magnetic potential at any place, they have calculated the magnetic forces produced at any point, first by the rotation of a small electrified area on the surface of the earth, and then, by summation, the force produced by the rotation of the whole electrified surface; and they have shown that these forces are the same as would be produced by certain definite distributions of attracting matter over the earth's surface, from which, by the use of spherical harmonics, they have arrived at the conclusion—that if the earth had an angular velocity of rotation around its axis w, and a uniform electric density σ, then there must be an electro-magnetic potential at any point inside the earth equal to—

$$\frac{4\pi}{3} 2\, \sigma\, w\, r \cos\theta,$$

and at any point outside the earth—

$$\frac{4\pi}{3} 2 \sigma w \frac{1}{r^2} \cos \theta,$$

where the unit of length is the earth's radius, r the distance from the earth's center of the place in question, and θ its co-latitude.

Now this electro-magnetic potential will be accompanied with certain magnetic forces varying from point to point, and the magnitude of these forces will depend on the interior constitution of the earth. As an example of their conclusion they examine what would be the distribution of magnetic intensity if the earth consisted of a hollow iron shell, and they have, using Poisson's formula, arrived at the following result:—If such an iron shell has an initial uniform charge of static electricity, and if it has an angular velocity of rotation round a diameter, then, independently of all other bodies in the universe, and independently of the coefficient of magnetization of the iron, there will be at any point on the surface of the sphere, having a latitude λ, a magnetic force proportional to—

$$\sqrt{1+3 \sin^2 \lambda}.$$

But this result is the same as that given by Biot's well-known law for the distribution of magnetic intensity on the earth's surface, hence giving considerable probability to their theory.

It is important to notice that in previous examinations of the earth's magnetism, it has been usual to start with the known law of distribution of magnetic intensity, and then deduce what arrangement of magnets, &c., inside the earth, would lead to this distribution; but, in this new theory of Profs. Perry and Ayrton, they start merely with an experiment described by Prof. Helmholtz, of the effects of a rotating electrified body, and show from this that the earth, by its rotation alone, *must* be magnetic, and next prove that if there be an iron shell, thick or thin, in the earth, then the distribution of magnetic intensity on the earth's surface will be the same as is known to exist from observation.

Next, as regards the sign of the electric charge on the earth's surface required to produce the earth's magnetic polarity—Is it in accordance with the known phenomena of atmospheric electricity? To produce the earth's magnetism we must have, in accordance with the known laws of electro-magnetism, a *negative* current flowing from west to east, or in the direction of rotation of the earth. In the language of the new theory, therefore, the surface of the earth must be *negatively* charged, but Sir William Thomson has proved, by observations with his electrometer, that all the phenomena brought to light by atmospheric electricity, on a fine day, would be observed just as they are if the earth had a *negative* charge.

Again, in order to get a rough approximation of what sum be the difference of electric potential between inter-planetary space and the earth, so that its own electric charge alone combined with its known rate of rotation round its axis shall produce the earth's magnetic moment, as determined by Gauss, Profs. Perry and Ayrton, take as an example, a solid sphere of iron of the size of the earth, and rotating with the earth's known rate of rotation, and they prove mathematically that something like a difference of potential a hundred million times the electromotive force of a single Daniell's cell would be sufficient for this purpose. They notice that there is no difficulty in imagining such a difference of potential to exist between the earth and inter-planetary space, seeing that there exists between the earth and the planets an enormous region of space having an insulation far higher than that of such a vacuum as experiment has shown will not allow the passage, from one point to another very near it, of a spark produced by a large induction coil.

Lastly, they draw attention to the fact that they have assumed the distribution of the electric charge on the earth's surface to be uniform, and so have arrived at a distribution of magnetic intensity dependent only on the latitude of the place, but that since it is possible that the sun and planets may have potentials differing immensely from that of the earth, it might be expected that the distribution of electric charge on the earth's surface, and consequently the magnetic intensity, would have variations like those of the tides, in fact, such variations as are known to exist; also, that it would be anticipated that any sudden formation of vapor on the earth's surface, or alter-

ation of the sun's atmosphere, or anything causing change in the lines of *static electric induction* from the sun to the earth ought to cause disturbances such as we know as magnetic storms. The alignments of planets with the sun and earth, again, or the proximity of planets to the sun having less than the average difference of electric potential from it, ought to diminish the disturbances in the solar envelope and produce the alteration of sun-spots and terrestrial magnetism which is known to accompany such planetary motions. And, lastly, the authors point out that the known lagging of changes in terrestrial magnetism behind variations in the sun-spots would be explained if the great pressure to which the iron in the earth's interior is subjected produces, as is very probable, considerable coercitive force, for such coercitive force would necessarily cause changes in the magnetic intensity to lag behind the disturbances in the earth's electric charge produced by alterations in the static induction of the sun and planets.

THE SLIPPING OF LOCOMOTIVE DRIVING WHEELS.

By P. OPPIZI.

From Abstracts of Papers published by Institution of Civil Engineers.

The slipping of locomotive driving-wheels has lately come prominently into notice, through the extensive trials recently conducted in France by M. Rabeuf, which have brought to light the fact that this phenomenon, so far from being occasioned merely by exceptional or accidental circumstances, is one of much more general occurrence in the regular working of locomotive engines than has hitherto been supposed. A slip varying from 13 to 25 per cent. on falling gradients, and increasing rapidly with the speed, as established by M. Rabeuf's trials, would appear an inexplicable anomaly, Signor Oppizzi considers, unless the co-efficient of adhesion between the wheels and rails, instead of being regarded as dependent simply upon the nature and condition of the surfaces in contact, be supposed to be also a function of a second independent variable, namely, the speed; and this element must enter into the co-efficient in such a manner, that when the speed increases beyond a certain amount the co-efficient itself shall diminish rapidly.

In treating the question of the slipping noted in M. Rabeuf's trials, MM. Desmousseux de Givré and J. Morandière, although admitting the hypothesis that the co-efficient of adhesion diminishes with increase of speed, appear to attach less importance to this; their view seems rather to be that the excessive slipping at high speeds is to be attributed to the unsteadiness of the mass suspended on the engine springs, its equilibrium being disturbed by the action of the steam and by the inertia of the moving parts, the effect of which would be to ease the loads successively off the several springs, thereby diminishing the adhesion. Whilst, however, Signor Oppizzi does not dispute that want of steadiness must interfere seriously with the tractive efficiency of a locomotive, neither does he therefore agree that, even if complete steadiness were attained, the slipping would thereby be got rid of, or be greatly reduced. Without having recourse to any such complicated arrangements as have been proposed for securing increased steadiness of the engine, the slipping, he is convinced, might be greatly diminished if more attention were devoted to better regulating the mode of action of the motive force, so that this should be utilized to the utmost extent, and in the best manner possible, by the adhesion available.

To this opinion he is led by what is matter of common observation in the working of locomotives: namely, that when the driving wheels are slipping al most continuously, it is by partially shutting the regulator, and by shifting the reversing lever to a lower grade of expansion, that the slipping is arrested and its recurrence prevented; and the object

is accomplished even better by these means than by sanding the rails.

From an analytical investigation, in which the obliquity of the connecting-rod is neglected, the Author shows that, so long as no slipping occurs, the well-known relation holds good between the engine power and the tractive resistance overcome by it: namely, that the product of the total mean effective pressure in the cylinders, multiplied by twice the length of stroke, is equal to the product of the whole train resistance (including that of the engine and tender), multiplied by the circumference of the driving wheel. On an incline, say of 1 in 200, the train resistance differs from that on a level to the extent of being augmented or diminished by the addition or deduction of $\frac{1}{200}$ part of the train's weight, according as the gradient is rising or falling.

This relation, however, based on the assumption that no slipping occurs, can only be relied upon to hold good so long as the train resistance, acting at the radius of the driving wheels, is kept so far below the limit of the adhesion acting at the same radius, as to leave a sufficient margin for allowing of the fluctuations in the engine power, which arise in each revolution from the combined effect of the varying steam pressure in the cylinders during each stroke, and of the varying leverage with which this pressure acts at the cranks. For security against slipping, therefore, it is not enough that the mean of the engine power, exerted during any revolution, should not surpass the adhesion available at the circumference of the driving wheels; but it is necessary farther to ensure this limit not being exceeded at the particular points at which the maximum power occurs in the revolution. The graphic method is accordingly adopted by the Author for practically solving this problem in any given instance. An undulating curve is plotted to rectangular co-ordinates, the abscissæ representing the lengths of arc described by the crank pin, while the ordinates are drawn proportional to the corresponding driving moments in successive angular positions of the cranks. The effective steam pressure, at successive points of the stroke, is either ascertained direct by indicator diagrams, or is calculated with the aid of a valve-motion diagram for various grades of expansion; and the leverage at the crank is found by a crank-motion diagram, in which the obliquity of the connecting-rod can be correctly included. The maximum ordinates to the curve are then seen, denoting the points at which in each revolution the engine-power attains its maximum. On the same diagram the moment of the available adhesion at the circumference of the driving wheels is represented by a horizontal straight line, which will preserve a constant height above the base line so long as the coefficient of adhesion between the wheels and rails remain constant; but when by higher speeds the coefficient becomes less, the horizontal line representing the adhesion moment will also drop to a correspondingly lower level. Whenever a maximum engine power or driving moment is in excess of the adhesion moment, slipping will ensue; and its extent will correspond with the magnitude and duration of that excess.

The result of M. Rabeuf's trials is considered by the Author to be in this way accounted for; and in his opinion that result unquestionably points to a much more comprehensive idea of the coefficient of friction than has hitherto obtained. As it was found in those trials, when running at a high speed, that the wheels made 20 per cent. more revolutions than corresponded with the distance actually run, it may safely be asserted that they must have been slipping continuously. The engine power must have been continuously in excess of what was necessary for simply maintaining the speed; and that excess did not go to augment the high speed already attained, but was absorbed by the resistance of the rubbing friction which the slipping called into play, and was thus converted into heat. The Author urges the great desirability of still more accurate experiments being carried out, with the aid of the improved indicators now available for such purposes; and suggests also that the slipping should be made to record itself simultaneously in the form of a combined or differential diagram, obtained by the relative motions of the driving wheels and the carrying wheels. Such a diagram of the slipping would throw more light on the problem of traction at very high speeds, the solution of which is

more and more demanded by the increasing development of railways.

By the aid of his calculations, together with the above graphic method of delineating the respective moments of the engine power and of the adhesion, the Author arrives at the conclusion that in an express engine, such as the one tried by M. Rabeuf on the Northern Railway of France, if the effective boiler pressure were only from 75 to 90 lbs. per square inch instead of 120 lbs., and if the steam were expanded through only a short portion of the stroke, it would be possible not only to avoid slipping at the high speed actually attained of 74½ miles per hour on a falling gradient of 1 in 200, but even to attain much higher speeds of running. In a three-cylinder engine, having cranks at 60°, or preferably at 120°, and with a still lower effective boiler pressure, the conditions would be yet more favorable for tractive efficiency. If the engine power exceed the resistance to the extent of say only 7,000 foot-lbs. in each revolution, the Author calculates that in five minutes the speed of the engine would be increased from 74½ miles per hour to 85¾ miles; while by an addition of 1 in 1,000 to the fall of the gradient the speed would, in five minutes, be increased from 74½ miles per hour to 79 miles, and to 84½ miles per hour if the additional fall were 1 in 500.

Applying the same mode of investigation to the express engine of the Paris, Lyons and Mediterranean railway, shown at the Paris Exhibition, with cylinders of 20 inches diameter and 26 inches stroke but an adhesion weight of only 24 tons, the Author concludes it will be necessary to use an early cut-off, between 25 and 30 per cent., otherwise the co-efficient of adhesion would be required to be exceptionally high. To maintain without slipping a speed of 46½ miles per hour on a falling gradient of 1 in 200, assuming an initial pressure in the cylinders of 127 lbs. per square inch, he calculates that in this engine a cut off at 25, 30, 35 and 40 per cent. of the stroke would require the corresponding co-efficient of adhesion to be 14.7, 17.5, 18.9 and 20.8 per cent. respectively.

In M. Mallet's compound-cylinder locomotive, having an adhesion weight of 15.2 tons, slipping is rather likely to occur when the two cylinders work independently, that is, each receiving direct the boiler steam of 140 lbs. per square inch effective pressure. The conditions are much more favorable for freedom from slipping when working really on the compound system with an effective boiler pressure of 100 lbs.; but the tractive power is of course considerably less in that case.

The general conclusions arrived at by the Author are:

Firstly, a more comprehensive expression should be taken for the co-efficient of adhesion, such as should render this co-efficient a function of the speed. The explanation of M. Rabeuf's experiments would then be, that if, when running at a high speed, any diminution of tractive resistance is not accompanied by a like reduction in the engine power, the latter, being thus left in excess, imparts to the wheels an accelerated rotation, which cannot produce a proportionate acceleration of the high speed at which the engine is already running, and hence gives rise to slipping.

Secondly, the results of M. Rabeuf's experiments are not applicable to low or moderate speeds, otherwise they would clash with the daily experience of practical working; therefore, into the expression so amended for the co-efficient of adhesion the speed must enter in such a manner that the term involving it shall vanish or be altogether insignificant at these lower speeds.

Thirdly, the tendency to continuous slipping depends upon the relation between the maximum moment of the steam pressure in the cylinders and the moment of the available adhesion, each estimated about the center of the driving wheels; and not upon what is commonly adopted as the criterion of slipping, namely, the relation which the mean engine power exerted during each whole revolution bears to the moment of the available adhesion.

Satisfactory progress is being made with the Port Victor, South Australia, breakwater. By means of a charge of dynamite, between 35,000 and 40,000 tons of granite were displaced on April 19, or double the quantity anticipated to be dislodged. Many blocks were moved weighing from 60 to 100 tons each.

OCEAN CURRENTS.

By Prof. ZOPPRITZ, of Giessen.

From "Nature."

Though for a long time the majority of seamen and geographers have firmly held the opinion that the great equatorial ocean currents derived their origin from the trade winds, yet, so far as I know, no attempt has yet been made to treat the physical problem of the propagation of surface-velocities downwards through a very thick stratum of water, with the means presented by the theory of the friction of fluids, as elaborated within the last thirty years. Such an attempt is all the more demanded as many authors have lately denied that surfare forces could set the sea in motion to any considerable depth. At the same time the most groundless assumptions have been set forth as to the depth of such drift-currents.

The essential principle of the theory of the internal friction of fluids is that when a plane stratum of water is moved forward, by any cause, in its own plane with a given velocity, the adjoining stratum cannot remain at rest, but, in consequence of its molecular cohesion experiences an impulse to move in the same direction. And if the velocity of the former stratum be continuous the latter assumes a velocity which tends to approximate constantly to the given velocity. This second stratum now exerts the same influence on a third adjoining stratum that it had to suffer from the first, and sets it in motion in the same direction. The third stratum draws with it in a similar manner a fourth, a fifth, and so on. The propagation of the velocity is only bounded by the limits of the fluid itself. If these limits consist of a solid plane parallel to the strata, then the propagation of the velocity will cease only at this point, *i.e.*, between the last liquid stratum and the first solid stratum.

The law according to which two neighboring strata of velocities mutually influence one another has already been demonstrated by Newton, and the accelerating force exerted by the friction has been assumed as independent of the pressure, and proportional to the difference of velocity. The latter theory of the friction of fluids carries out this fundamental hypothesis, as to the propagation of velocity between strata of the same medium which lie at an indefinitely small distance ξ from one another, and have accordingly only an indefinitely small difference of velocity Δ, inasmuch as it makes the acceleration produced by the friction, at the plane in which the strata meet, proportional to the quotient $\Delta : \xi$. The factor k, by which this quotient must be multiplied in order to give the acceleration, is called the *Coefficient of Internal Friction.*

The Newtonian hypothesis can be applied likewise to those parts of the bounding-surfaces of the fluid (where it is in contact with other bodies) which may possess independent motion. Here the acceleration produced by the limiting medium (which may be solid, fluid, or gaseous) is proportional to the difference of velocity which may in this case be finite. The factor of the proportion is called the *Coefficient of External Friction.* If the bounding body is a solid or even a fluid, then the fluid may wet it, that is, the stratum of fluid touching the limiting body may cling so fast to that body as to assume the same velocity. The coefficient of external friction is in this case infinitely great. This is the case between wood and water, glass and water; and, on the other hand, not so between glass and quicksilver.

The theory founded on this simple hypothesis has been subjected to the most varied experimental tests, and has, on the whole, been found to agree with the facts, so that the hypothesis may be regarded as proved.

In order to apply this theory to ocean currents, the simplifying presupposition has been made that the ocean is a mass of fluid contained between two horizontal planes at the distance h from one another, but in other respects unbounded. On the surface of this mass of fluid a wind of uniform strength and direction is acting at all times, while the under-

surface wets a solid plane, the sea-bottom, and is therefore always at rest.

We must not, however, look on the action of the moving air on the surface stratum of the water as proceeding according to the Newtonian hypothesis; it will act in this way only so long as the surface remains level.

But the wind produces waves and acts on them according to quite different laws. One fact of experience is available here, viz., that the surface-stratum of the ocean under the influence of a uniform wind, moves in the direction of the wind with a constant velocity dependent on the strength of the wind. If, therefore, we place on the velocity of the water at the surface the condition that it has a value w_0 at all times given, everywhere uniform, and of uniform direction, then the problem of the determination of the internal velocity becomes soluble.

But the simplifying presuppositions here assumed are almost realised in the central equatorial regions of the great ocean; the solution of the problem becomes, therefore, of deep interest.

The following are the chief results of the solution:—

If for an infinitely long time the surface-stratum has been kept at an unchanging velocity, then the whole mass of water is in a steady state of motion, *i. e.*, a state which no longer varies according to the time. The velocity w is then dependent only on the depth x beneath the surface and diminishes in proportion as the depth increases, till at the bottom it reaches *zero*. This relation is expressed by the formula

$$w = w_0 \frac{h - x}{h}.$$

Naturally it is presupposed that no other causes, *e. g.*, displacing currents, affect the motion of the deeper strata. If these deeper strata are kept by any foreign cause whatsoever in steady motion in a direction exactly opposite to the assumed motion, then at some point between the highest and the deepest strata there lies a plane where the velocity $=0$. If this plane lies at the depth h_1, then in the mass which lies above it the velocity follows the formula

$$w = w_0 \frac{h_1 - x}{h_1},$$

and is therefore in the same condition as if the strata that lie beneath were a solid mass,

It is specially noteworthy that the velocity is independent of the coefficient of friction, *i. e.*, that in the state of motion that prevails after an infinitely long time the distribution of the velocity is the same in a thin fluid like water and in a thick fluid like syrup. In the fixed state of motion, the influence of friction is shown by the participation of all the strata in the motion which is imparted from without to the surface alone. Dependence on the coefficient of friction takes place only on the consideration of motions that vary with the time, and affords a measure for the depth of penetration of a surface-impulse within a given time.

The formula which gives the velocity at the depth x of a mass of water originally at rest when for the time t the surface has been kept at a constant velocity w_0, has naturally a less simple form than the formula which was found for steady motions. (The formula is the same as that which determines the propagation of heat in a solid wall whose one side is kept at a temperature $w_0{}^\circ$, whilst the other remains at 0°.) From this formula results the simple law that any velocity whatever between o and w_0 prevails at different times at depths which are related to one another as the square roots of the times. I have used the formula to compute the time that a point at the depth of 100 meters requires to attain half the surface velocity, *i. e.*, $\frac{1}{2}\, w_0$. The coefficient of friction of the water was assumed according to O. E. Meyer's determination, at 0.0144, in which centimeters and seconds are the units of calculation. The result was that 239 years are required for the layer of water 100 meters deep to assume the half of the surface velocity. If it be asked what length of time is required for one-tenth of the surface velocity to penetrate to that depth, the answer is 41 years. Accordingly, the same velocities will be attained at a depth of 10 meters after 2.39 and 0.41 years respectively. In a more viscous fluid the resulting numbers would be smaller.

These numbers are well calculated to give an idea of the slow rate at which changes of motion are propagated downwards. For the numbers computed for the propagation of a given surface mo-

tion, hold likewise for the penetration of a change of the motion from the surface downwards, whose influence is simply added to the already existing motion. A steady current, therefore, whose velocity diminishes linearly according to the depth, will sustain only an extremely slight alteration (except in the strata nearest the surface) from passing changes of motion that affect the surface, *e. g.* from contrary winds or storms. There will prevail, rather, at every deeplying point of this current, a mean velocity that changes only very slightly according to the time, and which is determined by the mean velocity at the surface. This latter velocity has the direction of the prevailing wind, according to whose strength it varies by a law that cannot be more accurately settled.

If the surface velocity varies periodically according to the time, as is the case with all winds that depend on seasons and the hours of the day, then, after this periodic state has lasted an infinitely long time, the velocity at all depths is a periodic function of the time of similar period, but such that the amount of variation decreases rapidly according to the depth and that the occurrence of the maxima and minima is delayed proportionally to the depth. At a depth of 10 meters the amount of the yearly oscillation is already diminished to less than $\frac{1}{13}$th; at a depth of 100 meters it is beyond observation; at this depth the velocity is that corresponding to the steady state when the mean annual velocity is given to the surface. When the depths decrease in arithmetical proportion, the amounts of the oscillation decrease in geometrical proportion such that at four depths x_1, x_2, x_3, x_4, which stand in the relation

$$x_4 - x_3 = x_3 - x_1;$$

the amounts D_1, D_3, D_3, D_4, stand in relation

$$D_4 : D_3 = D_2 : D_1.$$

A maximum and the following minimum of the annual oscillation always exist at the same time at a vertical distance of 11.9 meters.

To give a conception of the time that a constant surface velocity which begins at the time $t=o$ requires, in order to bring the interior of an ocean 4,000 meters deep, which was previously at rest, to the state of steady motion, the following numbers will serve:—After 10,000 years there prevails at the half-depth, *i. e.*, at $x=2{,}000$ meters, just the velocity $0.037w_0$. Since, according to the already stated formula, in the steady state the velocity $0.5w_0$ must prevail at this point, it is easily seen how far the ocean is still removed after 10,000 years from the steady state. After 100,000 years the velocity at the depth stated is already $0.461w_0$, therefore very near the definitive value. After 200,000 years it differs only by two units in the third decimal place.

Among the results we have found, particular emphasis is to be laid on two, which seem more or less to contradict the views which have prevailed up to this time. In the first place, the steady motion arising in the interior of an unlimited stratum of water from an unvarying surface velocity makes itself felt with linearly decreasing velocity down to the bottom. Hitherto the view frequently expressed was, that the influence of surface currents, *e. g.*, the drift caused in the tropical ocean by the trade winds, reached only to very moderate depths. Secondly, it was found that all variations according to time, whether periodic or aperiodic, of the forces acting on the surface, propagate themselves downwards with extraordinay slowness, the periodic in very quickly decreasing amount. Taking both statements together, it follows that the movement of the chief part of a stratum of water exposed to periodically varying surface forces is determined by the mean velocity of the surface, and that the periodic variations are observable only in a comparatively thin surface stratum. From this it is obvious that hitherto the influence of the friction was undervalued in one direction, in so far, namely, as it was believed that its influence need not be considered as penetrating so deep, but in another direction it was overvalued, as too great an influence was wont to be ascribed to friction in respect of the propagation of varying current motions. Its effect was also very much overvalued in another point, viz., in respect of the action of a bank on a stream flowing along it. If, I repeat, the whole surface is kept at a constant velocity, then also in the current bounded at the side the distribution of velocity

in the steady state is independent of the coefficient of friction. Beyond that, the influence of the banks on the distribution of velocity is exceedingly slight.

A further result is that two steady currents flowing parallel to one another, but in opposite directions, in a fluid-stratum of constant depth, may very well graze one another without mutual disturbance. Their surface of division is then a vertical plane parallel to their direction in which the velocity O prevails, and which, therefore, stands to each current in the relation of a solid bank.

We have already shown numerically how extraordinarily slow the velocity existing at the surface is propagated downwards when the interior was previously at rest. Hence it may be concluded, *vice versa*, that when every point of the whole mass of fluid has at a given moment a given velocity varying according to the depth, and when from the same moment onwards the surface remains at rest, the effect of this initial state vanishes equally slowly, *i. e.*, the ocean passes into the state of rest with the same slowness with which in the first case the surface velocity was propagated into the interior. In fact the formulæ show that the times for the increase and decrease of the same fraction of the given velocity are expressed by the same number.

If from some cause or other strong currents had been generated in the ocean, say 10,000 years ago, these currents would certainly not have as yet disappeared, but would still be the chief agents in determining the movement of the ocean at great depths, supposing that the earth were completely covered by an ocean of the uniform depth of 4,000 meters.

The interruption by continents and islands of irregular form will contribute to weaken the effect of these former states of motion, not so much through the increased friction on the ocean-bed as through the reflex currents, which arise everywhere, crossing and impeding one another. But it must be observed after the above numerical proof the extremely slow spread of local alterations of motion over the interior mass, that the difficulties of an exact computation must not be shirked, on account of the traditional expression: "Friction quickly uses up all these velocities."

It would be possible to determine by observations whether effects of former movements are still present in the ocean. There would be required for this purpose only comparative current observations at the most varied depths, to be applied in the central parts of the great equatorial currents and of the region of calms. Yet, however, we dare not hope to be able to detect small remnants of interior motion with the same certainty with which the effect of the former high temperature of the earth, which disappears according to the same law, could be detected by subterranean observation of temperature, were one able to penetrate deep enough with the thermometer into the earth's crust.

The above computations give us also an idea how distant must be the time of the initial state. What a long time, for example, must we imagine the trade winds to have been blowing with their present extent and strength in order to be justified in assuming that the present state of motion of the equatorial currents is steady. For that about 100,000 years are needed, supposing we postulate a mean depth of 4,000 meters and do not take into account the deadening influence of continents and islands which must somewhat diminish that number. Every inirial state, whatever it may have been, vanishes finally, and gives way to a steady state, only the time varies which is required to diminish the originally arising velocity to any required degree of smallness.

We have several times made passing remarks on the American "telephonic exchanges," a useful and practical outgrowth of the introduction of the telephone. It does not seem to be generally understood that the system consists in the establishment of a central office, from which wires run out into the offices, warehouses, mills and residences of the subscribers. When one subscriber desires to talk with another, the central office is notified of the fact, his wire is connected with that of his neighbor, and communication is established. By this arrangement every subscriber is put in direct inter-communication.

—*The Engineer.*

THE CONSTRUCTION OF HEAVY ORDNANCE.

By JAMES ATKINSON LONGRIDGE, M. Inst. C. E.

From Selected Papers of the Institution of Civil Engineers.

III.

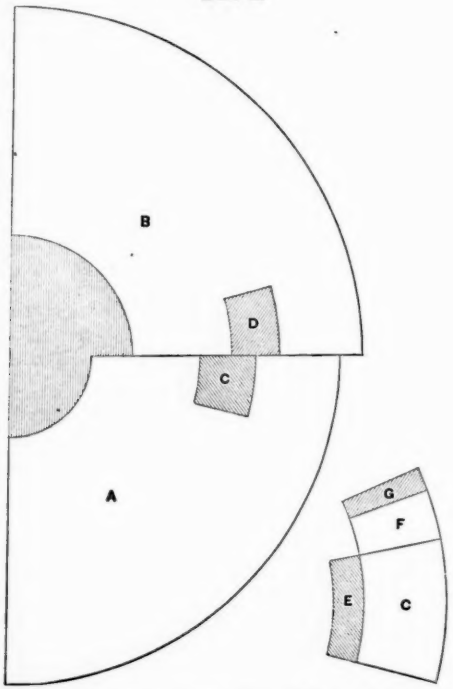
Mr. IMRAY said that was the third discussion he had attended at the Institution on the same subject. The first discussion was twenty years ago, when wrought-iron guns were scarcely thought about; the second turned very much upon the question whether guns ought to be of cast iron or of wrought iron; and now, at the third discussion, cast iron seemed to be altogether ignored. The members of the Institution and the country were greatly indebted to the Author for calling the attention of the engineers of England to the question of artillery.

There was no doubt of the fact that the present wrought-iron guns used in the English navy were not trusted by the sailors. After the terrible catastrophe that had recently happened, most of them felt that they would be safer outside the turret than inside. That was certainly an alarming state of things. At the time of the previous discussion, a commission was appointed by the American Government to visit all the arsenals and factories throughout the Continent, in order to ascertain what was being done. After careful investigation of the proceedings at Woolwich, Elswick, and elsewhere, the commission recommended the American Government to keep to their old cast-iron guns. The result was, that American ships were now armed with cast-iron guns of 12, 15, and 20 inches caliber, some of them delivering a blow twice as hard as any that could be given by wrought-iron guns. One of those guns, a 15-inch one, had been tried for endurance, and, after being fired 1800 rounds, was as good as ever. In the face of such facts it became a serious question whether the Government was right in making wrought-iron guns. Many persons had believed that the strain upon the interior of a gun was determined by the tensile strain of the metal of which it consisted. That was certainly a fallacy. That was not an occasion on which to enter into any discussion or calculation of what those strains were; but he might mention that, taking a strain of 20 tons upon the square inch inside a 12-inch gun, the utmost tensile strain that could be put upon the interior lining was 13 tons. Now it was well known that good cast-iron would stand 13 tons, and that with the present powders there was no such strain as 20 tons put upon the interior of a gun.

He might be permitted to direct attention to a diagram, Fig. 2. The lower part, A, represented part of the section of the gun before it was fired, and the upper B, showed the conditions of the parts at the time it was fired, of course much exaggerated. Taking the element of the metal of the gun as marked at C and D, that element was subject to three actions: first, it was compressed in itself; secondly, it was moved outward to an amount which was determined by the compression of all the metal outside; and thirdly, the circumference so pressed outwards had to be extended in proportion to the outward movement. Those three actions were what told upon every element of the metal.

Looking at the enlarged figure below, and taking C to represent that element of the metal before it was subjected to the pressure, it would be found that by mere compression to the amount marked by the inner part E, without any tensile force at all, a certain amount of the metal would be spread out lengthwise, as shown by F; therefore the tensile strain was not what was due to the total extension of the element, but only the extra extension marked at G—the quantity by which that must be extended more than the metal compressed into it would give. Adopting that mode of computation, he arrived at the result he had mentioned, that the strain inside the gun was not so great as might be imagined. That accounted for the fact that cast-iron guns had served, and still served better than almost any guns that had been used. He did not think that for that reason the manufacture of guns should be confined to cast-iron. At all events, it taught that the metal constituting a gun ought to be continuous; there should be no breaches of continuity from the inside to the outside. When there was a breach

FIG. 2.



of continuity, what happened? The two metals, however intimately joined by shrinkage, were in two different states; the outside of the inner metal was under compression, and the inside of the outer metal was under extension; and the result was, that every time the gun was fired the inner metal struck a blow upon the outer, so that a continual loosening and degradation took place, which in time would be so serious that the whole strength would be in the inner metal, without calling to aid the outer metal at all. Such were the serious consequences that had followed in some of those guns. Another curious fact was, that up to the time when wrought iron began to be introduced the British had exclusively cast iron guns; the largest were 68-pounders, and not one of them was known to burst under extreme strain. They stood remarkably well.

Of the last 3,000 guns delivered at the Arsenal, only seven burst on proving; the rest stood, and did service. In the American war only cast-iron guns were used: they were made with great rapidity, many of them of inferior metal and with bad workmanship; and only one Dahlgren gun gave way during the whole war; but a number of Parrott guns had given way. With those known facts, it was a serious question, for the country and for engineers, whether the present system of building up guns was right. He agreed with Dr. Siemens, that better material than cast iron should be used. If steel could be got, let it be had by all means; also the lining tube—not to take any strain, but merely to form a part that could be renewed when it was worn or cracked, and another substituted. He could not help thinking that engineers ought to give as much attention as possible to the theory of the question, in order to ascertain whether they were on the right or on the wrong tack in the employment of the present expensive system.

Mr. P. M. Parsons said the paper contained, first, a criticism of the Woolwich guns, and then a description of a gun which the Author considered would be

superior. He proposed first to remark upon the Author's own system. Two formulæ had been given in the Paper, one by Professor Barlow and the other by Dr. Hart, and they disagreed considerably. It was very unsatisfactory for a practical man to find two formulæ by eminent mathematicians disagreeing to such an extent, and the idea of taking as the true result something between the two appeared to him absurd. Either Professor Barlow's formula was right and Dr. Hart's wrong, or the the reverse, or they might both be wrong. They could not both be right, and to take anything between the two was childish. The difference between them consisted in the bases on which the calculation was commenced. Professor Barlow assumed that the metal was merely stretched, that there was no compression, that although a cylinder might alter its form the cross-sectional area of the cylinder would always remain the same; whereas Dr. Hart assumed that the metal was compressed, and that the compression was about the same as the extension. In the case of a tube that was stretched, all the metal was in tension, and it could not be compressed unless the metal was forced into itself, so that the specific gravity would be increased; and that appeared to him to be impossible. He thought Professor Barlow's formula was the correct one. He had always resorted to it, and had found that in practice the results agreed with the theory. The Author having founded his calculation upon a wrong formula, his criticism of the Woolwich guns must be erroneous. The principle of his own gun would not be, of course, affected, but merely the different strains or tension of wire, and so on, which could be adjusted when the right formula was adopted. It appeared to him that the building up of a gun by stengthening the tube by tension was bad. If a gun could be made in such a way that each ring or tube should take the strain due to it, without putting any initial tension upon it, or just a little to satisfy the different elasticities of the metals, as was done in his own guns, having a reinforced steel tube surrounded with a cast-iron jacket without any initial tension, that would be much better than attempting to compress the internal tube to the necesssry extent by an extensible metal outside. The Author's gun had an inner tube, as in the case of all guns which were built up, and he gave the choice of steel or cast iron. He hoped the Author would abandon cast iron altogether, because he was sure it would be uselesss. If a rifled gun with an interior bore of cast iron were fired with heavy charges, it would be soon cut to pieces. Moreover, a cast-iron tube of such size would never bear the pressure of so great an amount of steel wire wound round it: the tube would be crushed, and it would be of no use when subjected to alternate compression and tension caused by firing heavy charges. Taking a steel tube to begin with, there was no doubt that to wind wire round it with a proper amount of tension, each layer receiving its due share, would be the most economical way of applying the material to get direct strength out of it. If instead of that the steel was tempered in oil as much strength could be obtained, but a little more material would be required. From 25 to 30 per cent. more material would be needed in hoops of the ordinary size to get the same strength as in the Author's system, and that would only amount to an addition of about 5 per cent. on the total weight of the gun. Then the question arose whether all that complication paid, and whether the tempered-steel tube would not be more economical, and much easier to apply. One important defect in the proposed gun was the want of longitudinal strength in the inner tube. The Author evidently thought that there was no longitudinal strain upon the inner tube, or that the strain, whatever it might be, was taken up by putting a mass of cast iron at the breech end. That was an idea from which he totally dissented. If a gun tube had a projectile screwed into the bore, and a charge was ignited between it and the end of the bore, it would be admitted that, in addition to the circumferential strain, a longitudinal strain would be set up tending to pull the tube in two; but the same strain would occur if the projectile was free to move forward to almost the same extent. The hold on the tube would then be made up of, first, the pull of the projectile due to the rifling; secondly, the friction of the wad driven against the side of the bore, or, if no wad were employed, the friction of the gas rushing between

the projectile and the bore; thirdly, the friction of the gas rushing forward against the whole surface of the bore behind the projectile—the two last amounting to about the same as if a solid copper cylinder, fitting tightly into the bore, were being drawn out at the same velocity. There was nothing in the Author's gun to resist that strain except the strength of the tube itself. The wire would be no good, and the cast-iron casing was so thin that it would be of no use even if it laid hold of the tube; but the wire being continued all along to the muzzle, the cast-iron casing only abutted against it at the muzzle, and would be of no assistance to resist the strain set up at the breech end. If the mass of iron were taken away from the breech, and distributed round the exterior so as to bring the longitudinal strength of the cast iron to the tube, the gun, he believed, would be considerably improved. As a proof that the Author's idea of the longitudinal strain was erroneous, in a 12-inch gun there was a pressure at the moment of explosion of upwards of 4,000 tons, tending to blow the gun backwards. If the whole of that pressure were exerted in sending the gun back, it would be blown to the other side of the turret, whereas it was under complete control by the compressors and the weight of the gun. In a small-bore rifle the pressure set up inside was about 2 tons to the inch, which would give a pressure of 700 lbs. on the end of the bore, and if that pressure were effective in forcing back the rifle, no one would be able to fire it from the shoulder. The actual pressure of the recoil was only about 30 or 40 lbs., showing that a large portion of the pressure was absorbed in pulling the barrel forward. He should have been glad if the Author had entered into some of the practical details of the construction of his gun. There were difficulties that had occurred to him, which probably had been considered and overcome. In the 150-ton gun there would be about 32 tons of steel wire. Of course it could not all be drawn in one piece; it must have joints; and if there were joints there must be weak points, and if there were any weak points the whole thing would fail. With regard to the Author's criticism of the Woolwich gun, as it was based upon an incorrect formula, a great deal of what he had said was not applicable. Mr. Parsons was not there to defend the Woolwich guns; he did not agree as to the correctness of the principle upon which they were constructed, and there were many practical points in them which he condemned. But he thought the Author was in error in supposing that the officers in the Gun Factory were guided by the text book he had referred to in putting on the coils. There was plenty of mechanical and mathematical ability at Woolwich, and he believed all the coils were put on at a proper tension, or as nearly as they possibly could be by any mechanical engineer. It was hardly fair to assume that they were put on by one hard and fast rule. He had himself always assumed, in his criticisms, that the tubes and coils were put on with a proper amount of tension, so as to get the utmost amount of strength out of the metal. But when that was done, he still found that the Woolwich guns were not up to the mark for calibers above 9 inches. At the reading of Mr. Britton's Paper, in 1872, he stated that he had calculated the strength of the guns from 9 to 12-inches. The 9-inch gun would bear a strain of 24 tons to the inch when the metals were strained up to the elastic limit, and the 12-inch gun would bear a strain of about 28 tons. In calculating the pressure as indicated by the pressure gauge, and the respective weights of the projectiles, per square inch of bore, he found that, while the pressure in the 9-inch gun was 24 tons, in the 12-inch it was 36 tons. There was an increase of only 15 per cent. in the strength, whereas there was an increase of 57 per cent. in the strain. Therefore, if the 9-inch gun was only just strong enough the 12-inch gun must be too weak. That appeared to have been the case in the "Thunderer" gun, and he believed that a certain action was going on in the tube at that part which caused the gun to give way, which he would endeavor to explain. If the circumferential strength of the "Thunderer" 38-ton gun were calculated, it would be found that at the breech and C coil it would be about 28 tons per square inch at the elastic limit of the metals, taking the wrought iron at 10 tons, and the tempered steel tube at 28

tons per sqare inch. Of this the tube contributed about 10 tons, and the wrought-iron coils about 18 tons. If the circumferential strength at the point where the C coil ended was also calculated, it would be found that the strength suddenly dropped to 18 tons, of which the tube, as before, contributed 10 tons, and the B coil only 8 tons; and if the longitudinal strength of these two parts of the gun were also calculated, it would be found that, if the strength of the part surrounded by the C coil was represented by 100, the part beyond, owing to the halving together of the breech and B coils, would only amount to 22, or, taking the tube into account, as 100 to 44. There occurred, therefore, at this point a serious and sudden diminution of the support afforded to the inner tube, sufficient to account for its rupture even with ordinary charges; and the more so that, owing to the use of pebble powder, the maximum pressure would probably be developed when the projectile arrived about that point. The tube would be subjected to undue expansion, which would injuriously strain it circumferentially, and that expansion would set up a shearing action between that part of the tube thus unduly expanded and that part of the tube prevented from expanding by the superior support of 10 tons per square inch afforded to it by the C coil. At the same time, at this very point, it would be subjected to a greater longitudinal strain than in any other part of its length from the greatly diminished strength of the outer coils occurring at the same point. Whether or not the disaster on board the "Thunderer" was immediately caused by a double charge, it was evident to him that these guns were constitutionally weak, and would all burst after firing a certain number of rounds with battering charges. The question then was, what was to be done with those guns. He had said long ago that the only way to strengthen them was to put on an additional hoop of steel, by which they might be brought up to from 28 to 40 or 45 tons per square inch; but in that case it would be better to do away with wrought iron altogether, and put on a cast iron jacket, as then the guns, even if overloaded, would not burst explosively. This was proved by the test of his converted 68-pounder gun, which fired 163 rounds with charges of R. L. G. powder 20 per cent. heavier than the two charges combined, which were supposed to have burst the "Thunderer" gun, in proportion to the weight of gun, and besides these, two charges, which were 50 per cent. greater. All that had occurred was this: the inner tube expanded slightly beyond its elastic limit, but well within its breaking limit, and this was sufficient to burst the cast-iron casing, which quietly opened, showing a crack from the trunnions to the breech, thus giving palpable warning to cease firing, which warning being attended to, no explosive burst took place.

Mr. E. A. Cowper could not agree with the statement in the Paper: "It is generally admitted that a sudden change is equivalent in effect to double the amount of a steady strain, so that in the present case the effect would be equal to a steady strain of 55.06 tons per square inch." He did not believe that that was practically the case, nor generally admitted. If a weight came suddenly upon a piece of iron there was a certain small amount of excess of strain, due to that fall. In order to explain his meaning he had suspended a piece of india rubber with a weight at the bottom. It would be seen that when the weight was put on steadily it carried the india rubber down to a certain point, while if it were put on suddenly it went down lower, by the force of the momentum of the falling weight. That was the case of a falling weight; but it did not apply to a gun, where there was no falling weight. There was pebble powder lying close to the side walls of the gun. There was as much powder gas at the sides as in the middle; the gas neither moved from the center to the sides nor from the sides to the center. When the powder was fired, there was an elastic pressure against the sides of the gun, but there was no weight or motion, except at a speed due to the gradual burning of large pebble powder. Quick burning sporting powder gave greater speed and a greater strain. There was practically no momentum if he were to blow air into an india rubber ball. Every time the ball was blown into, it expanded a little, but there was no momentum. He did not believe that there was anything like a double strain on the metal due to the strain coming on at the speed it did with pebble-powder. If that were the

case, all the guns made on that principle would have burst long ago. It would not have been a question of degree of endurance: they would have burst at the first round. As a matter of fact, the Woolwich guns did not burst. It was all very well to calculate, and to say that they must; the fact was they did not. They had been made to burst by way of experiment, but those in actual service did not give way. The guns were much heated inside with quick firing, and he did not think that point had been sufficiently investigated. He did not know of exact experiments to ascertain the precise temperatures, and strains upon the rings and inside tube. The thinner the inner tube, the less it would bear the compression of hoops shrunk upon it; if the inner tube were much hotter than the hoops, the compression would be very severe indeed; and the thinner the hoops were, and the greater their number, and the thinner the tube, the greater would be the effect. In a Woolwich gun of course the solid metal conducted better than a greater number of hoops would do, and therefore the difference in strain was not so great. However a gun might be sponged, or water sent into it at great pressure, it was impossible to prevent the heat from getting through the body of the gun; and the hoops outside the steel lining would be very hot, and it was impossible to get at them. He could not agree with what had been said as to the increase in pitch. He had made the first rifling machine for Mr. Lancaster. The first rifled guns used in service were employed in the Crimean war; they were 68-pounders, and were of cast-iron. Mr. Lancaster wished to have a considerable increase in the pitch; Mr. Cowper endeavored to persuade him not to have it, and he now thought, as then, that an increase in pitch was wrong. A shot would increase in rotation as it increased in rapidity of motion forwards; when there was a great increase of pitch, the shot was apt to pull off the muzzle of the gun—a result which he had himself seen in several guns.

Captain R. A. E. Scott, R. N., said that Mr. Cowper's statement with reference to the increased twist was certainly true; and he might have added, that as slower-burning powders were being used there was no reason for rifling the guns with an increasing twist. One point, he thought, had been rather under-estimated, namely, the waves of pressure. Mr. Cowper appeared to think that there was no sudden wave of pressure in the gun. But in the trial of 7-inch guns (the rear end of the inner tubes of which were made circular) the rebound of the powder gases was so great after striking against the shot, that they positively bored through the breech-end of the inner tube. All the tubes were partly bored through at an early date, and the tube that was most bored into was that of the gun firing the expanding shot. In fifty rounds the inner tube of this gun was nearly cut through. The Paper was a very able one, and there was every reason for calling attention at the present time to the whole system of artillery. The Author thought that the present service guns were not strong enough—that they were so near the limit of their strength that a little more would burst them. He did not quite agree in this view, but concurred in what Captain Noble had said as to the suddenness of the pressure, and the short time it acted upon the inner part of the gun, admitting of a much greater strain than would really burst it if the shot were detained longer. But it was obvious that as the gun was so near its limit of elasticity, everything that tended to check the projectile in issuing out of the bore ought to be avoided. The projectile might be checked by indentation or erosion of the bore, by the fouling of the gun, or by an unequal yielding of the studs. The first effect of the pressure was, to crush the lower studs and push the service projectile down to the bottom of the bore. It was there shoved along, just as anything might be dragged over a dirty road; but if the shot had long flanges, it would rise, center itself, and run smoothly out of the bore. In an experiment which had been made with a smooth-bore cylindrical shot and a rifled one, the rifled shot went out of the gun at a greater velocity, and apparently more easily; but at that time the pressures were not measured. The Author had proposed a gun of very great strength. Without giving an opinion as to whether the wire system was the best possible, he had no doubt that for new guns it would be

desirable to have the great strength which wire would afford. He did not wish to criticise the details of the proposed plan, though many who had some knowledge of practical gunmaking could probably dispose of the solid portion of the metal in a better way. For himself, he had no fondness for cast iron. Notwithstanding what had been said as to the American guns firing heavy charges, the reports which had been received here showed that the charges for rifled guns were very low, and that the reason why the Dahlgren guns had not burst was, that they were not rifled. The smooth bore did not require the same strength as the rifled gun. The Parrott guns were not made of bad metal, but through being rifled they cracked and blew their muzzles off. It was scarcely correct to say that wrought-iron English guns had not burst. He recollected the "Shunt" gun bursting with a powder charge one-quarter the weight of the shot, and he was present when a 12-ton blew out its breech. He observed that the Author, in the case of the 150-ton gun, proposed a muzzle-loader, and in that he fully concurred. His experiments, however, were made with the breech-loader. In the details of its carriage, he thought there was a good deal that was not quite practical; but though he had not an intimate knowledge of metals, he had been immediately concerned with the mounting of guns, and so could assure the Author that it was necessary to have a high carriage in order to obtain room for sufficient elevation and depression, as well as for the appliances for working the guns. The carriages used at the present time, including those in the after turret of the "Thunderer," on which 35-ton guns were mounted, were as low as they could well be made. If they were lower, the gear would have to be out of sight. The whole subject was a national one, and if it increased the safety of the crew or the power of the ship they ought to have breech-loaders. But the facts of the case did not bear out this. The experience with Prussian guns, firing 6 lbs. of powder, afforded no criterion as to the results of firiug 150 lbs., 200 lbs., 250 lbs. and sometimes 400 lbs. of powder. A breech-piece would have to be enormously heavy to withstand such charges. The mechanism would occupy a great space, and there would be immense difficulty in handling it. But was it necessary to adopt breech-loading at all? He was confident that it was not. Several turret vessels were provided with 18-ton muzzle-loading guns; the "Glatton," "Monarch," and "Hotspur," with 25-ton guns; the "Devastation" with 35-ton guns; and in the after turret of the "Thunderer," 35-ton guns. Then it would be asked, "Why did the accident occur in the 'Thunderer'?" Simply because the loaders of the fore-turret were out of sight. It was true that there were fewer men inside; but the fact had not been sufficiently understood that the loaders were outside, so that the turret officer could not see what they were doing. Having mounted the muzzle-loading guns abovementioned, he might be permitted to say that no accident had happened with any of them. It was true that the system of hand-power and hand-loading was alone used, but there was not the slightest difficulty in applying steam gear also, and falling back upon the hand-gear if a valve or other appliance should fail. Although 35-ton guns were now mounted in the after turret of the "Thunderer," there would be no difficulty in putting in 38-ton guns and loading them in the same way. Those who had practical knowledge of the working of heavy guns on board ship had foreseen the danger of loading from the lower deck, and he believed that the accident had occurred just as the Committee had reported. As to muzzle-loading by the ordinary method, there were advantages in it which had been much overlooked, apart from its security. In firing, the gun was usually slightly elevated, and, when it recoiled, it was loaded at once from the muzzel without any alteration of the elevation. The present pebble powder gave an enormous mass of dense smoke. The result would be that the enemy could not be seen; and hence, if the elevation had to be changed for the purpose of loading, the next shot would be likely to fail. This was an important point in favor of muzzle-loading. He did not think that a large breech-loading gun would be found to be safe in the hurry of close action at night; nor did he think that the experiments about to be carried on in Prussia would convey any correct

criterion as to the safety of the plan. A 72-ton breech-loading gun might be worked in daylight, and no accident might occur; but in a turret, men could not see well, and the officer would need a hundred eyes to overlook what was done so as to prevent accident with a breech-loading apparatus. Prussian naval officers had told him that they had great difficulty in keeping the breech of their heavy guns tight, and that they preferred muzzel-loaders. He believed the present British service guns were good and serviceable, and would be safe if existing obstructions were removed, so that the shot might glide steadily out of the bore. With regard to the inner tube, if it were made thinner he did not know but it would stand better. His own experience was, that the thinner the tubes the stronger they were in proportion; and he believed if a tube were drawn with rifling in it, it would be still better. He did not think any solid metal could be adopted which would be superior to Sir Joseph Whitworth's compressed steel; and therefore either this alone, or in combination with wire, was the direction which should be pursued in making new guns. He did not see much force in the arguments that had been advanced against the Author's wire system.

Mr. W. H. Barlow, Vice-President, said it might be thought that the Author's ingenious specimen of a wire gun had been put forward at the Institution as a complete novelty, but it was not so. When at the Philadelphia International Exhibition of 1876, he saw exhibited a specimen of the Woodbridge gun, made on the same principle. The gun was described in the report of Major W. H. Noble, R.A., a judge of that department. It appeared that the Woodbridge gun was not altogether a new one, as it was said to date as far back as 1850. In 1865 a trial was made of a 2½-inch gun which demonstrated its great strength and endurance, and another trial was made in 1872. He had not heard how the gun shown at the Exhibition had behaved. He desired to mention these facts in order that it might not be thought that the Instituiion was unaware of the existence of such guns.

Mr. Longridge, in reply, observed that the principle he advocated had been brought before the Institution by himself eighteen years ago. The breech-loading gun now exhib.ted was made and fired in 1860; and in 1867, in a Paper which he had sent to the Institution, but which was not read, there was an exact description of the gun, with drawings. Questions of priority were never satisfactory, and he did not wish to enter into them. His object in bringing the matter again before the Institution was not to advocate anything new, because his propositions were much what they were nineteen years ago, but he had carried them out into a practical form. The objections then raised were not against the principle, but as to the impossibility of giving a practical form to his proposals. He had again brought the subject forward in order to show that it was not simply a scheme which had entered into his brain, but that he had considered all the necessary details. It was not simply a matter of theory: but, like all true theories, a matter which could be easily and economically reduced to practice. Several speakers had referred to the subject of formulæ. General Sir John Lefroy did not dispute that formulæ were of some use; but he said that at Woolwich facts were preferred to formulæ, "that mechanics were governed not by formulæ, but by facts," and that "experience taught much more than formulæ." He begged to differ from Sir John Lefroy. Formulæ could be nothing but an expression in symbolical language of absolute truth. If a formula was not that, it was a false formula; either the mathematics were wrong, or the data which were constants in the formula were wrong. It had been said that half-a-dozen formulæ had been brought forward, but in truth there were only two. One was that of Professor Barlow, which any one who examined it could see was wrong, because he assumed the area of the ring to be constant.

His own formula, Dr. Hart's, M. Lamé's, and Dr. Hopkinson's were identical. Dr. Hopkinson had kindly pointed out that he had omitted to take one element into consideration. When there was a tensile force and at the same time a normal compressive force, there was a tension arising out of the latter which he had not taken into account. To have done so would have complicated the

formula, and he felt that the effect would be inconsiderable. He was pleased, however, that Dr. Hopkinson had worked it out to the rigid formula; and the result was that, instead of a tension, in an extreme case of 17 tons, he had found the tension to be 18¼ tons. Guns might, of course, be calculated upon that more exact formula, but the labor of calculation would be much increased without materially altering the result. Sir John Lefroy had stated that the guns at Woolwich were quite perfect; and other speakers, especially Mr. Cowper, had repeated the statement. He had for a long time kept a list of Woolwich guns which had their tubes split; he had, unfortunately, lost it; but, by way of an appeal to facts, he would refer to an extract from the Quarterly Report of the proceedings of the department of the Director of Artillery, minute, 34,636, 16 : 3 : 77. The Superintendent of the Royal Gun Factory reports "that, on examination of 30 : 12 : 76 of the experimental 80-ton gun, it was found that the steel tube was cracked, the split being in one of the rifle grooves; widest at 70 inches from bottom of bore, about the position of maximum pressure, and extending about 15 inches along the groove in both directions. An incipient crack appears in the opposite groove. He will forward a more detailed report." Two months afterwards the Director of Artillery forwarded the foregoing Report to the Secretary of State for War, remarking "that the crack is unfortunate, but shows the great strength of the structure. The gun has fired one hundred and sixty-six rounds, and, although the tube cracked, the gun itself has not given at all. The experimental 35-ton gun had a split tube after sixty-eight rounds, and the gun was fired in that condition for five rounds, and, although the crack increased, the gun itself showed no signs of damage. The gun was designed to pierce a 20-inch plate at 1000 yards. It was calculated that this gun, with a 16-inch caliber, firing 300 lbs. of powder and 1,700 lbs. projectile, would effect this. The experiments point out that this effect will be obtained. The Explosive Committee, finding that an addition to the charge greatly increased the power of the gun without giving any great increase of strain, proceeded to fire the gun with much increased charges, so that sixty-nine out of one hundred and sixty-six rounds have been fired with 370 lbs. of powder. The Director of Artillery has no reason to doubt that this is the cause of damage. Valuable information has been obtained, and the gun has shown great strength and endurance." After some further rounds, he continues: "Third crack discovered. Thinks gun is slowly breaking up." That was one of the facts upon which, he presumed, Sir John Lefroy relied to defend the system of Woolwich construction. It was a fact that might have been predicted by any person who had made the calculations upon the assumption that the statements in the text book as to the shrinkage of 1 in 1,000 were correct. It had been stated that that text book was not worked by at Woolwich, and that it had been drawn up by two or three young gentlemen who had just left the Royal Military Academy. On the contrary, it was a book published by order of the Secretary of State for War. The previous edition had been written by Captain Stoney and Captain Jones—one the Assistant Superintendent, and the other Captain Instructor, in the Royal Gun Factory. The present edition was written by Major John F. Owen, Captain Instructor in the Royal Gun Factory; and it also was published by order of the Secretary of State for war. The book professed to give an exact account of the work at Woolwich. Major Owen was not a young man who had just left the Royal Military Academy, but one of the gentlemen recently sent to Malta to report upon the "Thunderer" gun. The book was only published last year, and it ought to be accepted as evidence of what was done at Woolwich. If it had not been so he should not have brought the book before the members. It had been urged against his own proposal that he had not put the heavy material of the gun in the right place. He had tried to explain that there could be no longitudinal strain upon the inner tube of the gun; but it appeared that he had failed to make himself intelligible, at any rate to Mr. Parsons, because, although Fig. 9 showed that the breech was closed, not by a solid tube, but by a plug free to move, only abutting against the iron, Mr. Parsons

persisted in saying that the strain must come upon the tube itself, and would blow the breech out, whereas there was no strain whatever. By removing the four bolts and applying pressure, the breech plug could be pushed out of the tube altogether. It was exactly the same in the breech-loading gun exhibited. There was no strain on the chase, except a compressive strain, due to the action of the shot, which was very slight, tending to force the chase of the gun forward. It had been stated that it was impossible, according to his plan, to give sufficient longitudinal strength. On the contrary, this was a simple matter; there were two solid side rods which could be made of any desired strength. In the case of a large gun he proposed to make them of steel plates laid side by side. One speaker had stated, that there was a weight of 4,000 tons acting upon the breech; if it were 10,000 tons, all that would be needed was to make the side rods of a sufficient area so as to give no more than 3 tons or 4 tons per square inch. That was easy and simple, and it avoided all the complication of strain which Dr. Hopkinson had pointed out as arising wherever an attempt was made to have two strains at right angles in the same piece of iron. In large breech-loading guns that would be found a serious matter. Dr. Siemens said, "One great drawback to the Author's proposed system, which he himself admitted, was that he had a resistance against bursting strain without resistance in the longitudinal direction." The Author did not admit this to be a disadvantage; instead of a drawback, it was a great advantage, as the system, especially for large breech-loading guns, afforded facility of construction and safety. He would now refer to other criticisms of Dr. Siemens. If Dr. Siemens were right in his conclusions his objections would be very serious; but he thought he could show that Dr. Siemens was entirely wrong. He had misrepresented (not intentionally) that he had, in giving his idea of a gun constructed on the Woolwich principle, referred to a 9-inch gun with a tube 8 inches thick, and with 28 inches of iron outside. It would be seen from the Paper that it was not a 9-inch but a 16-inch gun. The gun was not such a gun as he would propose to make; but, his object was to show that a gun could be made with the same number of hoops as a Woolwich gun, and yet no hoops would be strained more than 10 tons per square inch. Dr. Siemens had mistaken the radius of the bore for the thickness of the tube: the radius was 8 inches, the thickness 6.39 inches. The iron outside the two tubes was 28 inches. Fig. 6 showed the exact tensions, both before and during explosion. The compressive strain was not confined to the steel tube: it extended to the steel tube and to the first iron tube, and it was exactly balanced by the tension of the outer tube. Dr. Siemens and other speakers seemed to think that necessarily the whole compression must be thrust upon the inner tube; but that was a mistake. It was an error to suppose that the great tension he would put on would crush the inner tube. He could put any compression or tension upon it that he liked. In the case of the large 150-ton gun which he had proposed, the cast iron would never be under more than 12 tons compression. When it was fired it would not have more than 3 tons tension, yet it would stand an internal pressure of 24 tons to the square inch. He could not then stop to demonstrate it, but if any one would examine the formula he would see that it was so. He had not said, as alleged by Dr. Siemens, that a shrinkage of 1 in 1000 was not sufficient for such a gun, but that the shrinkage was a governing factor, a most important one, and that it must depend upon the modulus of elasticity of the materials, and the dimensions of the rings. A gun-maker might say: "I will make a gun with a shrinkage of 1 in 1000;" but then the rings must be proportioned to that shrinkage, and that could not be done without a formula. He had referred to a sentence in the text book, with regard to which he had said it was difficult to imagine a more complete confusion of ideas than that which pervaded it. Dr. Siemens, in his criticism, had alluded to the wrong sentence, namely, that "guns of present construction, ... during the process of shrinking." There was no confusion of ideas in that sentence, and it was not that to which he referred. The sentence which he had criticised was: "Much will depend upon the thickness and strength of the coil to be shrunk on, for the heavier it is the tighter will be

its grip, and the more will the inner parts be compressed and supported; whereas a thin weak coil would probably suffer from over tension." It was of that sentence he had said "a more complete confusion of ideas could not exist;" and he still maintained it. He next came to another objection which, if Dr. Siemens were correct would certainly be serious, although it might be provided against. Dr. Siemens seemed to think that by the heating of the gun after firing all the tensions would be thrust adrift and destroyed. That was an error arising from a misapprehension of the cause of the heating of the guns. It was not caused, or only to a small extent, by the combustion of the powder. Even assuming the powder-flame to be at a temperature of 5000°—which was the outside it had ever been taken at—and that it was in contact with the chase of the gun during the whole time the shot was in it, say $\frac{1}{100}$ second—which was also beyond the mark—the total amount of heat absorbed would be $\frac{1.5}{100}$ unit per square foot acting upon about a ton of metal in a large gun; consequently it was impossible that the heating could arise from the flame: it arose from the sudden state of tension into which the material was thrown. If a bullet was squeezed in a vise it would become hotter. If mechanical energy was employed in any way in compressing material, heat was produced.

The heating of the guns, therefore, was not appreciably due to the flame, but to the severe tension produced in the material. That was the point on which his gun had so great an advantage over others. The tensions became at the end uniform throughout. The guns could be made so that when they were hot they were absolutely perfect with regard to their tensions, and when they were not hot they were slightly weaker than they would otherwise be. He had calculated that weakness, and it was inconsiderable. With regard to Dr. Siemens' proposal, he could not think that it was practical. Possibly Dr. Siemens' had in his mind the Rodman gun, which was cooled from the inside when in a fluid state. He had proposed to make a cylinder gun, to put it in a furnace, to raise it to a high temperature, about 600° Centigrade, and then to cool it in the inside to 60°. He had no hesitation in saying that in the case of a 12, 18 or 20-inch gun that was physically impossible. If air were sent through it at zero, the internal surface would never be below 579°; if cooled with water at freezing point, it would never be below 500°. The material could only give off a certain amount of heat from the inside, and it took a certain amount of heat from the outside, which was three or four times as large. But even if the proposal could be carried out, what would happen? The gun might be kept ten hours in the furnace; and no doubt, while the cooling was going on, and the outside was hot, there would be a varying strain throughout the gun. But when it was taken out to cool (it could not be cooled from the inside right through, as in the Rodman gun) what would happen? The gun would go back to the original condition: the 12-inch bore which was expanded would go back to 12 inches; the 24-inch bore to 24 inches. He therefore maintained that Dr. Siemens' plan was physically impossible. If it were possible, he would only arrive at an approximation, and then at an enormous expense.

He would now briefly refer to the remarks of Captain Noble. In the first place, he desired to give all credit and honor to his friend Mr. Charles Henry Brooks, who had made all the mathematical calculations for him. That fact had been stated in his former Paper, and he did not refer to it again because he thought it was so well known. Captain Noble stated that he agreed with a great many of the theoretical views in the Paper, but he could not agree that the description of the procedure at Elswick ought to be regarded as correct. Mr. Longridge had given no description of it; he had not said a word about Elswick except what was extracted from the Woolwich text book to which he had referred. He presumed that the writers knew what was going on at Elswick; if not, they ought to apologize to Elswick. Captain Noble had stated that calculations were made at Elswick at the present time. It would be in the recollection of many members that Sir William Armstrong, nineteen years ago, said there was no attempt at making calculations; but at present it appeared they were made. Captain Noble stated that the calculated shrinkages were greatly modi-

fied by the results of a long series of experiments. He protested against that as utterly unscientific. If the formulæ was right, the shrinkages must be the right ones, and it was impossible to strengthen the gun by departing from those shrinkages. He was glad, however, to find that rules were now applied at Elswick. He believed that the Elswick guns were far superior to the Woolwich guns, because at Woolwich the authorities had made a far greater departure from theory, and in fact had set all theoretical considerations at naught.

The remarks made by Mr. Canet were exceedingly valuable. He had evidently thoroughly studied the subject, and he had shown that his formula was identical with M. Lamé's. Mr. Canet's calculations appeared to be generally right, and it was gratifying to find that the formulæ had been practically and successfully applied in France. He had heard that statement several years ago; and he had since been informed that the guns (7 and 9-inch) had been successful, and that it was possible the French Government might adopt the system with larger guns. With regard to the suddenness of a strain, he believed that it had a considerable effect. Mr. Cowper was in error in imagining that, because the space in which a weight acted was not great, there could not be any momentum. He forgot that, although the space was exceedingly minute, there was a space, and the velocity was enormous. He forgot that the strain was applied in about $\frac{1}{6000}$, or $\frac{1}{600}$ second, and that the velocity of the wave pressure was above 20,000 feet per second in steel. It was not a question as to whether the space moved through could be seen with the eye; there was velocity and pressure, and consequently energy. No doubt the law of increased strain existed to a certain extent, but to what extent he could not say. In his calculations, though he mentioned the law, he had not taken advantage of it in his criticisms upon the Woolwich guns, but he had taken the simple statical strain, putting aside altogether the increased strain due to the suddenness of the application of the pressure. He would only add that, although he had no longer anything but a scientific interest in the matter (which was perhaps the best interest a man could take in it), nothing would please him more than to see his ideas brought into practice in this country. The theory had never been disputed, and no real practical objections had been made to his proposals in the form in which he had submitted them.

Mr. Barlow, Vice-President, observed, through the Secretary, that the Author, in his concluding remarks, made a statement not contained in the Paper itself, namely, that the late Professor Barlow was wrong in the formula he gave for strains generated in cylinders by internal pressure, the Author's opinion being based on the supposition that the specific gravity of metal underwent alteration under strain. A bar extended by tension undoubtedly diminished in sectional area. Whether the diminution of section area was such as to maintain the specific gravity without alteration had not been ascertained. There were no experiments, so far as he knew, which established the fact that any alteration of specific gravity arose from strain, even in the case of a simple strain like that of direct tension. But supposing, for argument sake, that tensile strain might, to a small extent, decrease the specific gravity, compression ought, by the same reasoning to increase it. In the case of the gun both these forces or strains were operating; each lamina conveyed its action to the next one outside it, by pressure acting in lines radiating from the center; and, therefore, whilst the strains arising in the circumferential lines were tensile, those acting in the radial lines were compressive, so that as regarded the question of specific gravity they would counteract each other. It appeared, therefore, that there was no sufficient reason given for pronouncing Professor Barlow's formula to be wrong.

Colonel Shakespear remarked, through the Secretary, that, without expressing an opinion on the merits of the Author's mode of construction, the following statement in a tabular form from authentic documents, relative to the heavy artillery of England, Germany, France and Russia, showed that the former country was behind hand; for it would be seen that whilst a shot from the German 12-inch gun of 36 tons had a velocity of 1,385 feet per second after it had

gone 1,000 yards, the corresponding English gun—the 12-inch of 35 tons—only had a muzzle velocity of 1,300 feet per second: and as regarded the energy of the shot after a flight of 1,000 yards, the figures were thus:—Germany, 8,672 foot-tons; France, 8,433; Russia, 7,325; and England, only 6,946 foot-tons.

	Nature of Gun.	Length of Bore.		Charge.	Weight of Projectile.	Muzzle Velocity.	Velocity at 1,000 Yards.	Muzzle Energy.	Energy at 1,000 Yards.	Remarks.
		In.	Cal.	lbs.	lbs.	Ft. per Sec'nd	Ft. per Sec'nd	Foot Tons.	Foot Tons.	
English muzzle-loading rifled guns.	12-in. of 35 tons	162½	13.5	110.0	700	1,300	1,196	8,200	6,946	Rifled on Woolwich system; 9 grooves; twist increas' from 0 to 1 in 35 calibers.
	12 " 25 "	145	12.0	85.0	600	1,300	1,179	7,030	5,780	Two patterns; nine grooves; twist 1 in 100 to 1 in 50 calibers
	11 " 25 "	145	13.2	85.0	535	1,315	1,199	6,415	5,335	One thick coil over breech; 9 grooves; increasing from 0 to 1 in 35 calibers.
	10 " 18 "	145½	14.5	70.0	400	1,364	1,228	5,160	4,185	Two c'ils over bree'h; 7 grooves; increasing from 1 in 100 to 1 in 40 calibers.
	9 " 12 "	135	13.9	50.0	250	1,420	1,236	3,496	2,648	5 patte'ns of this gun,
	8 " 9 "	..	14.8	35.0	180	1,413	1,213	2,492	1,837	all with 6 grooves.
	7 " 7 "	126	18.0	36.0	115	1,561	..	..	..	Armstrong construc-
	7 " 6½ "	..	15.9	30.0	115	1,525	1,261	1,855	1,268	tion; three grooves.
German breech-loading rifled guns.	14 " 56 "	270	19.3	253.0	1157	1,665	1,550	22,330	19,270	Steel.
	12 " 36 "	227	19.0	132.0	650	1,525	1,385	10,510	8,672	"
	11 " 27 "	207	19.0	132.0	520	1,640	1,483	9,699	7,934	"
	10 " 22 "	225	22.5	104.0	414	1,575	1,410	7,112	5,706	"
	10 " 18 "	174	17.0	104.0	414	1,509	1,362	6,553	5,322	"
	9 " 15 "	178	20.5	60.0	306	1,502	1,330	4,786	3,753	"
	9 " 14 "	157	17.0	60.0	306	1,476	1,309	4,622	3,633	"
	8 " 10 "	163	22.0	37.5	217	1,394	1,223	2,925	2,253	"
	8 " 9 "	119	14.0	33.0	206	1,312	1,127	2,458	1,830	"
	7 " 5½ "	149	21.9	26.5	119	1,509	1,280	1,876	1,351	"
	7 " 5 "	131	19.3	22.0	119	1,411	1,202	1,643	1,191	"
	7 " 4 "	135	19.5	..	..	..	..	..	..	"
French breech-loading rifled guns.	13.4 " 48 "	..	13.4	..	..	..	..	..	..	New exp'mental steel.
	12.6 " 38 "	204	16.6	139.0	770	1,371	1,257	10,057	8,433	Cast iron and steel.
	11 " 20 "	167	15.4	53.0	476	1,188	1,046	4,659	3,610	" "
	11 " 22 "	194	18.0	88.2	476	1,378	1,247	6,275	5,130	" "
	11 " "	..	..	92.0	476	1,525	1,377	7,671	6,259	Steel.
	9 " 14 "	165	17.5	35.0	317	1,188	1,027	3,103	2,317	Cast iron and steel.
	9 " 14 "	165	17.5	62.0	317	1,427	1,265	4,575	3,517	" "
	9 " 11 "	165	17.5	84.0	300	1,558	1,370	5,057	3,903	" "
	8 " 8 "	138	18.0	18.0	165	1,168	991	998	718	" "
	8 " 8 "	138	18.0	33.0	165	1,486	1,272	2,533	1,881	" "
Russia' b.l. rifled guns.	12 " 40 "	204	17.0	113.0	650	1,398	1,275	8,830	7,325	Steel.
	11 " 27 "	187	17.0	82.0	495	1,360	1,229	6,346	5,182	"
	9 " 14 "	152	17.0	47.0	270	1,541	1,181	3,365	2,612	"

The above were the principal known guns; but Italy, Austria and Turkey had powerful guns; whilst China and Japan were adopting, and possibly making in their own workshops, a powerful artillery after European pattern. America had adopted the "Palliser" system of construction. Indeed all the nations of the earth were busy on their artillery, Italy seemed to prefer muzzle-loading

guns on the Armstrong system, and had the largest gun of all, and which had been made at Elswick, viz., a 100-ton gun; but this gun, as well as the English 81-ton gun, was still experimental. The following results had been obtained with them: The 100-ton gun, with a charge of 500 lbs. of Italian powder, and a projectile of 2,000 lbs., gave a muzzle energy of 38,000 foot-tons; and with 463 lbs. of English powder, a muzzle velocity of 1,627 feet per second; and energy, 36, 700 foot-tons. The 81-ton gun, with a charge of 423 lbs., and projectile of 1,700 lbs., gave a muzzle velocity of 1,620 feet per second; at 1,000 yards, of 1,518 feet per second; and a muzzle energy of 29, 935 foot-tons. Both the above were muz zle-loaders. The table showed that length of bore was necessary to velocity. The projectile of a breech-loaded being larger than the bore, centered itself in the bore, whereas with the muzzle-loader that was not so. This disadvantage to the latter been overcome by the introduction of "gas checks." Mounted as guns were at present, muzzle-loading had the advantage in the rapidity of fire. The only practical advantage breech-loaders had over muzzle-loaders was, that less space was required for loading; hence breech-loaders could be generally the longer, to the more profitable consumption of heavy charges. Land-service guns might be of any length, but at sea space was limited.

Dr. SIEMENS explained, through the Secretary, that the Author in his reply had stated that Dr. Siemens had mistaken the radius of his normal gun with hoops for the thickness of the inner tube; and in this he was perfectly right. But considering that the radius of the hypothetical gun was 8 inches, and the thickness of the inner tube 6.3902 inches, the correction only served to strengthen the argument, to the effect that, under the shrinking system there was danger of crushing the inner tube by the tensile strain of the greater mass of metal composing the hoops. True, the Author maintained that the shrinkage of succeeding layers of hoops might be so regulated that the first layer would habitually be under compression, and thus aid the inner tube to resist compression. He had not overlooked this possibility, but endeavored to prove that such nice adjustment of original tensions in the different parts constituting the guns would be upset, and rendered illusory, on account of the heating of the inner tube by the act of firing the gun.

The Author admitted this portion of the argument, but said that it was based upon a misapprehension of the cause of heat in firing guns. The products of combustion of the gunpowder, though taken at a temperature of 5,000°, would not, he asserted, communicate more than one unit of heat to every square foot of inner gun surface during the short interval of $\frac{1}{100}$ second when the heat would be active in firing, an amount of heat which would certainly be inappreciable in its effect upon the large mass of the gun. But in order to account for the great heat undoubtedly produced in firing, he ascribed it to the compressive action communicated to every portion of the fabric in firing. So far from agreeing with this view, Dr. Siemens ventured to assert that not a single unit of heat would be set up in the body of the gun by such compressive action, so long as the metal was not strained beyond its elastic limit. The elastic action of a watch-spring would not give rise to heat, although the continued bending of a non-elastic wire through the same angles of range would cause it to heat rapidly. In the one case the work expended in bending the spring was recovered, and in the other it was lost, and its equivalent of heat put into its place. He maintained that all the heat produced in firing a gun was due to the heated products of combustion, and that the Author misapprehended entirely the amount of heat taken up by a metallic surface from a dense current of highly heated material, even in so short an interval as $\frac{1}{100}$ second. The heat produced by successive firing must indeed cause strains in the gun far exceeding those originally created by shrinkage, because every 130° Fahrenheit must produce in an iron or a steel cylinder under confinement a strain of 12 tons per square inch; and it was well known that a few shots would suffice to produce that degree of temperature in the inner tube, unless powerful means of internal cooling were resorted to. The Author's criticism of the mode proposed by him of distributing the strains in massive hoops or cylinders, in such a

way as to make them capable of resisting a maximum of bursting strain, was based upon the same misapprehension of the heating, or, in this case, cooling, effect of a dense and active current upon metallic surfaces. If water were to be the medium employed, and the tube was of a temperature below that at which actual contact was prevented by spheroidal condition, the innermost surface of the cylinder under operation would almost instantaneously assume the temperature of the cooling current, the heat-absorbing action of which would be limited only by the conductivity of the metal itself limiting the inflow of heat toward the center. This cooling action would be kept up until the whole mass was cooled from within. The conditions of varying tension aimed at could not be realized unless the temperature of the external surface was kept up to the last; and in this respect the plan here proposed differed essentially from that followed by Captain Rodman in cooling his cast-iron guns, which metal was moreover much less susceptible than steel to the mode of treatment, owing to its short elastic range.

Mr. Robert Wilson observed, through the Secretary, that the principle upon which the Author's formula was based was that steel and iron were ductile, and elongated when subjected to tensile stress. One element had, however, been overlooked by the Author, without which the property of ductility could not be brought into play. This was the element of time. The formula was approximately correct, theoretically, for hollow cylinders subjected to a steady hydraulic or steam pressure, where the tension increased gradually from zero, and allowed time for the exercise of ductility. But he considered the Author was in error when he assumed that the formula was equally applicable to the strength of cylinders exposed to a great pressure very suddenly applied, where there was no time for the exercise of ductility, or for each layer in the thickness to take its share of the pressure, as was implied in the formula. In addition to the sudden circumferential pressure exerted by a large charge of gunpowder, there were also still more severe local pressures. In the experiments with the 10-inch gun, it was found that these local pressures were as great as 63 tons per square inch. They acted like blows, and their energy was mainly expended upon the inner surface of the tubes, without producing any great circumferential pressure upon the outer surface or the coils beyond. In the Paper the Author only once mentioned that the explosion pressure was sudden, and that its effect might be double that of a steady pressure; but he did not appear to see that it affected the very principle upon which this formula was founded, and not merely the relative value of the terms and factors in the formula. The Author censured the Woolwich and Elswick gunmakers for not using his formula. This censure and his reasonings were based upon two assumptions: 1st. That guns always failed from longitudinal fracture of the tube. Now this assumption was not borne out by facts, as solid, coiled, and tubed guns, of cast iron, wrought iron, bronze, and steel, had failed by fracture transversely near the breech, and not always longitudinally, in this country, on the Continent, and in the United States. 2nd. That the longitudunal fractures were always and only due to circumferential tension, exerted by the pressuse of the gases. Now this was opposed both to experience and theory, for the severe local pressures, which acted like blows on the inner surface of the tube, were more trying to the resistance of the material than the steady strains assumed by the Author. Sir W. Armstrong, in his evidence before the 35-Ton Gun Committee, stated that his guns failed always in the tube, and that the steel tubes failed from the shock, the jar, or the concussion. He did not appear to consider the circumferential stress at all. It was probable that most of the fractures found in steel tubes were the development of the surface cracks produced by the local blows of the explosion, and by the great and sudden changes of temperature to which the inner surface of the tube was exposed. The temperature of the gases was about 4,000° Fahrenheit. Although the time to which the metal was exposed to this high temperature was infinitesimal, and although the quanity of heat was small notwithstanding its intensity, the heat had been found sufficient to account for the melting of soft particles of metal in bronze and cast-iron guns. It was there-

fore not unreasonable to conclude that the severe local pressures or shocks acting upon steel tubes exposed to a high temperature were sufficient to start the surface cracks found in the steel tubes of large guns. It appeared to him that no strengthening of the tubes by shrinking on coils, or coiling on wire with any degree of tension according to the formula, which was only intended to meet the case of a steady and gradually applied load, would prevent the formation of these surface cracks. When a surface crack was once started, no matter how, either longitudinally or transversely, the jarring and shocks to which the tubes were subjected at every discharge would inevitably cause the crack to extend in a homogeneous metal like steel or cast iron, and ultimately bring about complete fracture. The homogeneity of ductile steel rendered it in some respects much superior to wrought iron as a constructive material. Yet it was this very homogeneity that rendered steel so unsuitable when it could not be guaranteed against incipient fractures in positions where it was exposed to shocks, jars, concussion, or vibration. In wrought iron an incipient fracture would often alter its course, or stop altogether at the first cinder, or break in the structure it met with, and it was but little affected by subsequent jarring; but in steel, no matter how ductile, a crack once begun was sure to extend rapidly by jarring till complete fracture ensued. However, owing to its superior resistance to detrusion, abrasion, and erosion, steel was, on the whole, the best material for gun tubes: and as it could not be expected soon to meet with a better material, the best should be made of the material. It appeared to him that any attempt to increase the life of large guns should be in the direction of cushioning the blow given by the explosion of the powder. This could probably be done by leaving a sufficient air space all round the charge; and with suitable powder this cushioning need in no way reduce the velocity of the shot, but might actually be made to increase it. In order to carry this out properly, recourse, however, must be had to breech-loaders. In seeking to devise a remedy for the failure of the steel tube of large guns, it appeared to him that the Author had ignored the cause or causes to which the failure in the first place was due. He would apply an external remedy, where only an internal remedy could reach the root of the malady. In applying mathematics to the solution of any question on the strength of materials, there was nothing so misleading as figures, excepting facts; and for this reason—it was extremely difficult to get at all the facts which went to the making up of a problem and when all the facts were ascertained, it was still more difficult to "condition" them (so to speak), and to assign to each its proper position and value.

Mr. LONGRIDGE replied, through the Secretary, that Mr. Barlow's observation respecting Professor Barlow's formula did not convince him that he was in error in pronouncing that formula to be wrong. It was a mathematical question and he was content to leave it as it was, supported as he was by such authorities as M. Lamé, Dr. Hart, and Dr. Hopkinson. As regarded Dr. Siemens' explanation, he regretted that that gentleman should repeat his assertion about the hypothetical 16-inch gun. If he had looked at Fig. 6 he would have seen how erroneous such an assertion was. To make the matter perfectly clear, the following table showed the strains in this gun before and during the explosion, with an internal pressure of 24 tons per square inch:

		Before Explosion.	During Explosion.
Steel tube.	Inner surface	—9.946	10.000
	Outer "	—6.510	— 1.734
First ring.	Inner "	—1.110	10.000
	Outer "	—1.933	2.121
Second ring.	Inner "	5.966	10 000
	Outer "	3.352	5.620

So far from there being any fear of crushing the inner tube, it would be seen that it was never under a compression greater than 10 tons per square inch. Dr. Siemens repeated his assertion about the destruction of the tensions by heating, and said that the Author admitted this portion of the argument. He did nothing of the kind. What he did say

was this: "If Dr. Siemens were right in his conclusions, his objection would be very serious; but he thought he could show that Dr. Siemens was entirely wrong." He still adhered to that statement. With reference to the question of heating, he could not accept Dr. Siemens' dicta. Did Dr. Siemens mean to assert that if a steel anvil was struck with heavy blows from a steel hammer, both being elastic, and receiving no permanent deformation, no heat would be evolved? If so, he made an assertion which he might satisfy himself was contrary to fact. Neither could he accept Dr. Siemens' assertions about the quantity of heat that would be absorbed into the body of the gun from the powder gases, nor about the cooling a cylinder from the inside, under the conditions proposed by Dr. Siemens. With all respect, he must formally deny the correctness of such assertions, and hold by every iota of what he said in his general reply, based as it was upon such authorities as Rumford, Peclet, and Cauchy. Finally, he would repeat, that this question of heating had long ago had his careful attention, that it could be practically met without difficulty, and especially in the wire system of construction.

ELEMENTS OF THE MATHEMATICAL THEORY OF FLUID MOTION. PART II.

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II.

§ 2.

We have seen that if we have a velocity potential φ that the stream lines are normal to the surface φ=const., and have for their differential equations

$$dx : dy : dz :: \frac{d\varphi}{dx} : \frac{d\varphi}{dy} : \frac{d\varphi}{dz}.$$

Suppose that we assume

$$\varphi = a$$

then the surfaces given by the equation φ=const. are those of the ellipsoids u=const., since for u=const. we have a=const. Now our stream lines are the lines normal to this surface, and they are given as the intersection of the two hyperboloids v=const. and w=const. It is a known fact in the theory of these orthogonal surfaces that the intersection of any two of them is a line of curvature on both; thus the stream lines in the case under consideration are the lines of curvature common to the two hyperboloids for which v=const. and w=const. On each of the systems of surfaces there is, as is well known, two systems of lines of curvature. In the case of the ellipsoid they are the intersections of this surface with each of the confocal hyperboloids. The surface of flow is made up of lines of flow as we have before seen, as there is no motion in the direction of the normal to this surface. Now if we take $\varphi = \beta$ we shall have for our stream lines the intersections of the system of ellipsoids u=const., and the hyperboloids of two nappes for which w=const. The fluid will in this case occupy that portion of space which is exterior to the ellipsoid, and is limited by the surface of the corresponding hyperboloid of two nappes.. It may assist the imagination of the reader to conceive these surfaces for which we have φ=const., to be, as they are, the equi-potential surfaces which Maxwell speaks of in his treatise —and the stream lines—to be the lines of force, then the direction of the stream line at any point is the same as that of the resultant force at that point. If there is no other force than fluid pressure, the direction of the fluid pressure at any point is the direction of the stream line. Now take the case of $\varphi = \beta$ that is for the hyperboloid of one nappe v=const. This is to be an equi-potential surface, the fluid pressure is every

where normal to it, that is, the stream lines are the intersections of the confocal ellipsoid with the confocal hyperboloid of two nappes. In like manner if $\varphi = v$ the stream lines are normal to $w = \text{const.}$, and the lines of curvature are common to the ellipsoid and hyperboloid of one nappe. The fluid may fill the space bounded by one of these hyperboloids. Now for the velocity in each of these three cases. We have for the square of the velocity when $\varphi = a$

$$\left(\frac{da}{dx}\right)^2 + \left(\frac{da}{dy}\right)^2 + \left(\frac{da}{dz}\right)^2 = \frac{4}{(u-v)(u-w)}$$

or we have also

$$\left(\frac{da}{dx}\right)^2 + \left(\frac{da}{dy}\right)^2 + \left(\frac{da}{dz}\right)^2 = \frac{4}{(a^2+u)(b^2+u)(c^2+u)\left\{\frac{x^2}{(a^2+u)^2} + \frac{y^2}{(b^2+u^2)} + \frac{z^2}{(c^2+u)^2}\right\}}$$

This velocity then is in general finite, becoming infinite however in the focal ellipse

$$\frac{x^2}{a^2-c^2} + \frac{y^2}{b^2-c^2} = 1$$

for which $u = v = -c^2$ For $u = \infty$ we saw that one ellipsoid became a sphere whose radius $= \sqrt{u}$. Now in this case the above expression for the square of the velocity becomes equivalent to, calling r the radius of the sphere,

$$\frac{4}{r^2(x^2+y^2+z^2)} = \frac{4}{r^4}$$

or the velocity is

$$= \frac{2}{r^2}.$$

We saw that if in our expressions for a, β, γ, we make $k = o$, that is, $a = b$, that our hyperboloids of two nappes become the meridional planes

$$\frac{x^2}{\cos^2\lambda\gamma} - \frac{y^2}{\sin^2\lambda\gamma} = o$$

and the hyperboloid of one nappe become

$$\frac{x^2+y^2}{\cosh^2 i\lambda\beta} - \frac{z^2}{\coth^2 i\lambda\beta} = 1$$

so now our lines of curvature or stream lines become the meridian curves of this hyperboloid of revolution, that is, they are hyperbolas lying in planes passing through the axis of z.

These hyperbolas have for their foci the point, of the circle

$$x^2 + y^2 = a^2 - c^2$$

which is the form now assumed by the focal ellipse. It is obvious that a stream line passes through every point of the surface bounded by the focal ellipse, and that they cut this surface at right angles, the plane of xy being a normal plane to all of the surfaces. If u becomes infinitely great the surface of the ellipsoid becomes that of the infinitely great sphere, and the lines of flow normal to its surface are of course right lines from the origin. We can see also from our values given for x^2, y^2, z^2, in times of a, b, c, and the parameters u, v, w, that the ratios of x, y, z, in the case of $u = \infty$ will be independent of this quantity, and consequently the stream lines are right lines drawn from the origin. The direction of the motion at any point may be either of the two directions of the lines of curvature, but there can be no sudden change of direction in the interior of the fluid; if there be a surface, however, that separates one portion of the fluid from another, it is possible that on opposite sides of this surface the motion shall be in opposite directions. The direction of the motion is defined by the quantities

$$\frac{\frac{da}{dx}}{\sqrt{\left(\frac{da}{dx}\right)^2 + \left(\frac{da}{dy}\right)^2 + \left(\frac{da}{dz}\right)^2}} \quad \frac{\frac{da}{dy}}{\sqrt{\left(\frac{da}{dx}\right)^2 + \left(\frac{da}{dy}\right)^2 + \left(\frac{da}{dz}\right)^2}} \quad \frac{\frac{da}{dz}}{\sqrt{\left(\frac{da}{dx}\right)^2 + \left(\frac{da}{dy}\right)^2 + \left(\frac{da}{dz}\right)^2}}$$

these being the direction cosines of the direction of $\sqrt{\left(\frac{da}{dx}\right)^2 + \left(\frac{da}{dy}\right)^2 + \left(\frac{da}{dz}\right)^2}$

Now in order that the direction of the motion shall change, it is necessary to give to a as defined by the equation

$$a=\int_u^\infty \frac{du}{\sqrt{(a^2+u)(b^2+u)(c^2+u)}}$$

the opposite value; that is evidently equivalent to giving the opposite sign to the radical

$$\sqrt{(a^2+u)(b^2+u)(c^2+u)}.$$

This can only change its sign by passing through the value zero; it has this value in the focal ellipse for which $u=-c^2$. Now if the surface bounded by this ellipse be not a limiting surface in the fluid, there will necessarily be a change in the direction of the motion by passing through the surface, as $-c^2$ is the smallest value that u can have, and consequently du takes the opposite value in passing this point. There is no other place in the fluid where such a change of sign, and consequently of direction of motion can take place except at this plane, and as it *must* take place here, it flollows that this plane must be a limiting plane in the fluid, that is, separates from each other those portions of the fluid in which the motion takes place in opposite directions. In the case of $\varphi=\beta$ we have for the square of the velocity

$$\left(\frac{d\beta}{dx}\right)^2+\left(\frac{d\beta}{dy}\right)^2+\left(\frac{d\beta}{dz}\right)^2=-\frac{4}{(v-w)(v-u)}$$

this is infinite in two cases, viz: for $v=w=-b^2$, giving as the focal hyperbola

$$\frac{x^2}{a^2-b^2}-\frac{z^2}{b^2-c^2}=1$$

and also for $v=u=-c^2$ which again gives the ellipse

$$\frac{x^2}{a^2-c^2}+\frac{y^2}{b^2-c^2}=1$$

These lines are not in the interior of the fluid, but at its limits, as they are the limiting cases of the ellipsoid and hyperboloid of two nappes which form the bounding surfaces of the fluid. Finally for $\varphi=\gamma$ the velocity is

$$\left(\frac{d\gamma}{dx}\right)^2+\left(\frac{d\gamma}{dy}\right)^2+\left(\frac{d\gamma}{dz}\right)^2=\frac{4}{(w-u)(w-v)}$$

which is infinite only for $w=v=-b^2$ that is for the focal hyperbola, as before this curve does not lie in the interior of the fluid, being the limit to which the hyperboloid which forms the boundary of the fluid, approaches as w approaches the value $-b^2$. Suppose in this case of $\varphi=\gamma$ that we have k indefinitely small, that is, $a-b$ an indefinitely small quantity. The stream lines will then be the intersections of the surfaces

$$\frac{x^2+y^2}{\operatorname{cosec}^2\lambda\alpha}+\frac{z^2}{\cot^2\lambda\alpha}=a^2-c^2$$

$$\frac{x^2+y^2}{\operatorname{cosech}^2 i\lambda\beta}-\frac{z^2}{\coth^2 i\lambda\beta}=a^2-c^2$$

or the circles

$$x^2+y^2=\frac{\coth^2 i\lambda\beta+\cot^2\lambda\alpha}{\operatorname{cosh}^2 i\lambda\beta+\cos^2\lambda\alpha}\,(a^2-c^2)$$

whose centers lie in the axis of z and whose planes are perpendicular to this axis. We know that w lies between $-a^2$ and $-b^2$, and therefore now differs by an infinitesimal quantity from $-u^2$; so replacing it by $-a^2$ we have for the square of the velocity

$$\frac{4}{(a^2+u)(a^2+v)}.$$

We had for x^2 and y^2 the expression

$$x^2=\frac{(a^2+u)(a^2+v)(a^2+w)}{(a^2-b^2)(a^2-c)}$$

$$y^2=\frac{(b^2+u)(b^2+v)(b^2+w)}{(b^2-c^2)(b^2-a^2)}$$

Now for $w=-a^2$ and $a^2=b^2$ we have on adding these

$$x^2+y^2=\frac{(a^2+u)(a^2+v)}{a^2-c^2}$$

from which for the velocity results

$$\sqrt{\frac{4}{(a+u^2)+(a^2v)}}=\frac{2}{\sqrt{a^2-c^2}\,\sqrt{x^2+y^2}}$$

Suppose that we have an ellipsoid in the fluid and that it is fixed. As before, φ denotes the velocity potential, and for the space outside of the ellipsoid then satisfies the equation

$$\triangle^2\varphi=o$$

At the surface of the body we must evidently have

$$\frac{d\varphi}{d\nu}=o$$

ν denoting the direction of the normal. Assume for φ the value

$$\varphi=\mathrm{G}\frac{d\Phi}{dz}-cz$$

when G is a constant and Φ is the potential of the ellipsoid at any exterior point, and is given by the equation

$$\Phi=\pi abc\,q\int_{o}^{\infty}\frac{1-\frac{x^2}{a^2+\chi}-\frac{y^2}{b^2+\chi}-\frac{z^2}{c^2+\chi}}{\sqrt{(a^2+\chi)(b^2+\chi)(c^2+\chi)}}d\chi$$

From this value of φ we evidently have at infinity

$$\frac{d\varphi}{dx}=o\quad\frac{d\varphi}{dy}=o\text{ and }\frac{d\varphi}{dz}=-c$$

or at infinity the motion is in the negative direction of the axis of z, and the velocity is $=-c$. Now we must determine G so that the condition at the surface of the body

$$\frac{d\varphi}{d\nu}=o$$

may be fulfilled. Denote as before the interior normal by ν_1 the exterior by ν_2. We have now as the conditions to be satisfied

$$\frac{d\varphi}{d\nu^2}=\mathrm{G}\,\frac{d^2\Phi}{d\nu_2 dz}=\cos(\nu_2 z)$$

But we found

$$\frac{d^2\Phi}{d\nu_1 dz}+\frac{d^2\Phi}{d\nu_2 dz}=4\pi\cos(\nu_1 z)$$

From this multiplying by G and transposing

$$\mathrm{G}\,\frac{d^2\Phi}{d\nu_1 dz}=[4\pi\mathrm{G}-1]\cos(\nu_2 z)$$

It is more convenient to have the differential coefficient with reference to the internal than the external normal. Now for an interior point we have

$$\Phi=\pi abc\int_{o}^{\infty}\frac{d\chi}{\sqrt{(a^2+\chi)(b^2+\chi(c^2+\chi)}}$$

$$-\pi abc^3\int_{o}^{\infty}\frac{d\chi}{\sqrt{(a^2+\chi)(b^2+\chi)(c^2+\chi)}}-\&c.$$

Now let

$$\mathrm{A}=abc\int_{o}^{\infty}\frac{d\chi}{(a^2+\chi)\sqrt{(a^2+\chi)(b^2+\chi(c^2+\chi)}}$$

$$\mathrm{B}=\int_{o}^{\infty}\frac{d\chi}{(b^2+\chi)\sqrt{(a^2+\chi)(b^2+\chi)(c^2+\chi)}}$$

$$\mathrm{C}=\int_{o}^{\infty}\frac{d\chi}{(c^2+\chi)\sqrt{(a^2+\chi)(b^2+\chi)(c^2+\chi)}}$$

A, B and C are constants, and we can thus write Φ in the form

$$\Phi=\text{const.}-\pi(\mathrm{A}x^2+\mathrm{B}y^2+\mathrm{C}z^2)$$

and from this

$$\frac{d\Phi}{dz}=-z\pi\mathrm{C}z$$

and

$$\frac{d^2\Phi}{d\nu_1 dz}=-2\pi\mathrm{C}\frac{dz}{d\nu_1}=2\pi\mathrm{C}\cos(\nu_2 z)$$

our equation of condition will now be satisfied by making

$$\mathrm{G}=\frac{1}{2\pi(2-\mathrm{C})}$$

We may now examine the stream lines in the case when we have the velocity potential given by

$$\varphi=\frac{1}{2\pi(z-\mathrm{C})}\,\frac{d\Phi}{dz}-z$$

the quantity before denoted by c is not essential, so we can make it $=1$. The equations of the stream lines are

$$\frac{dx}{\frac{d\varphi}{dx}}=\frac{dy}{\frac{d\varphi}{dy}}=\frac{dz}{\frac{d\varphi}{dz}}$$

The general integration of these equations is manifestly very difficult. When the ellipsoid is of revolution $a=b$ we may suppose φ to be a function of only two variables, ρ and z, where

$$\rho=\sqrt{x^2+y^2}$$

now

$$\frac{d\varphi}{dx}=\frac{d\varphi}{d\rho}\,\frac{d\rho}{dx}=\frac{x}{\rho}\,\frac{dx}{d\rho}$$

$$\frac{d\varphi}{dy}=\frac{d\varphi}{d\rho}\,\frac{d\rho}{dy}=\frac{y}{\rho}\,\frac{d\rho}{d\rho}$$

also

$$\frac{d^2\varphi}{dx^2}=\frac{d^2\varphi}{d\rho^2}\,\frac{x^2}{\rho^2}+\frac{d\varphi}{d\rho}\,\frac{(\rho^2-x^2)}{\rho^3}$$

$$=\frac{d^2\varphi}{d\rho^2}\,\frac{x^2}{\rho^2}+\frac{d\varphi}{d\rho}\,\frac{y^2}{\rho^3}$$

$$\frac{d^2\varphi}{dy^2}=\frac{d^2\varphi}{d\rho^2}\,\frac{y^2}{\rho^2}+\frac{d\varphi}{d\rho}\,\frac{x^2}{\rho^3}$$

Now the expression for $\Delta^2\varphi$ becomes

$$\Delta^2\varphi=\frac{d^2\varphi}{dz^2}+\frac{d^2\varphi}{d\rho^2}+\frac{1}{\rho}\,\frac{d\varphi}{d\rho}=o$$

This can be written since $\frac{d\rho}{dz}=o$

$$\frac{d}{dz}\left(\rho\,\frac{d\varphi}{dz}\right)=-\frac{d}{d\rho}\left(\rho\,\frac{d\varphi}{d\rho}\right)$$

Take now one of the equations of the stream lines

$$\frac{d\varphi}{dy}dx-\frac{d\varphi}{dx}dy=o$$

this clearly becomes

$$xdy-ydx=o$$

which gives

$$\frac{x}{y}=\text{const.}$$

from this we see that every stream line must lie in a plane passing through the axis of z. From the equation $\rho^2=x^2+y^2$ we have

$$xdx+ydy=\rho d\rho$$

also $$xdy-ydx=o$$

from these

$$dx=\frac{x\rho d\rho}{x^2+y^2}=\frac{xd\rho}{\rho}$$

Now take the other equation of the stream lines it is

$$\frac{d\varphi}{dz}dx-\frac{d\varphi}{dx}dz=o.$$

Substituting for dx and $\frac{d\varphi}{dx}$ their values this becomes

$$\frac{d\varphi}{dz}d\rho-\frac{d\varphi}{d\rho}dz=o.$$

But we saw that

$$\frac{d}{dz}\left(\rho\frac{d\varphi}{dz}\right)=-\frac{d}{d\rho}\left(\rho\frac{d\varphi}{d\rho}\right)$$

consequently ρ is an integrating factor of this equation, and the quantity on the left of the equation

$$\rho\frac{d\varphi}{dz}d\rho-\rho\frac{d\varphi}{d\rho}dz=o$$

is an exact differential. Now those results shew us that there must be some function U such that,

$$\frac{d\mathrm{U}}{dz}=\rho\frac{d\varphi}{d\rho},\quad\frac{d\mathrm{U}}{d\rho}=-\rho\frac{d\varphi}{dz}$$

and consequently

$$\frac{d\mathrm{U}}{dz}dz+\frac{d\mathrm{U}}{dz}d\rho=o$$

Thus U=const. is the integral of

$$\rho\frac{d\varphi}{dz}d\rho-\rho\frac{d\varphi}{d\rho}dz=o$$

and is the equation of the stream lines. If we can find another function V such that

$$\frac{d\mathrm{V}}{dz}=\varphi$$

and $$\Delta^2\mathrm{V}=\frac{d^2\mathrm{V}}{dz^2}+\frac{d^2\mathrm{V}}{d\rho^2}+\frac{1}{\rho}\frac{d\mathrm{V}}{d\rho}=0$$

we can write

$$\mathrm{U}=\rho\frac{d\mathrm{V}}{d\rho}.$$

From this

$$\frac{d\mathrm{U}}{dz}=\rho\frac{d\varphi}{d\rho}$$

$$\frac{d\mathrm{U}}{d\rho}=\rho\left\{\frac{1}{\rho}\frac{d\mathrm{V}}{d\rho}+\frac{d^2\mathrm{V}}{d\rho^2}\right\}$$

$$=-\rho\frac{d\varphi}{dz}$$

Thus our equations for $\frac{d\mathrm{U}}{dz}$ and $\frac{d\mathrm{U}}{d\rho}$ are satisfied, and we can write the equation of the stream lines

$$\rho\frac{d\mathrm{V}}{d\rho}=\text{const.}$$

Take now the two equations

$$\varphi=\mathrm{G}\frac{d\Phi}{dz}-z$$

$$\varphi=\frac{d\mathrm{V}}{dz}$$

They give

$$\frac{d\mathrm{V}}{dz}dz=\mathrm{G}\frac{d\Phi}{dz}dz-zdz$$

Integrating

$$\mathrm{V}=\mathrm{G}\Phi-\frac{z^2}{2}+\mathrm{C}_1$$

this satisfies the first condition for V; the second, viz: $\Delta^2\mathrm{V}=o$ will be satisfied by making

$$\mathrm{C}_1=\frac{\rho^2}{4}$$

So we have finally

$$\mathrm{V}=\mathrm{G}\Phi-\frac{z^2}{2}+\frac{\rho^2}{4}.$$

From this

$$\frac{d\mathrm{V}}{d\rho}=\mathrm{G}\frac{d\Phi}{d\rho}+\frac{\rho}{2};$$

therefore the equation of the stream lines

$$\rho\frac{d\mathrm{V}}{d\rho}=\text{const.}$$

becomes

$$\rho\left\{ G\,\frac{d\Phi}{d\rho}+\frac{\rho}{2}\right\}=\text{const.}$$

This for the ellipsoid of revolution around the shortest axis c. Now suppose

$$a=b=c=R$$

that is, the ellipsoid becomes a sphere of radius R. Then for the potential of this sphere at an external point we have as is well known

$$\Phi=\frac{4\pi}{3}\,\frac{R^3}{r}$$

When r is the distance from the center of the sphere to the external point x,y,z;

or $$r=\sqrt{x^2+y^2+z^2}=\sqrt{z^2+\rho^2}$$

Now

$$\frac{d\Phi}{dz}=-\pi 2zC$$

this gives $C=\frac{2}{3}$, and consequently $G=\frac{3}{8\pi}$

Substituting in

$$\varphi=G\,\frac{d\Phi}{dz}-z$$

and we have for the velocity potential

$$\varphi=\frac{R^3}{2}\,\frac{d\frac{1}{r}}{dz}-z$$

also $$\frac{d\Phi}{d\rho}=-\frac{4\pi}{3}\,\frac{R^3}{\rho^3}\rho$$

therefore we have for the equation of the stream lines

$$\rho^2\left\{1-\frac{R^3}{r^3}\right\}=o$$

which being satisfied either by $\rho=o$ or $r=R$ shows us that the stream lines are those functions of the axis of z outside the sphere $\rho=o$, and since we do *not* have $r=\pm R$, the other stream lines are *semi-circles* cut from the sphere by planes through ρ and the axis of z. We have for the components of the velocities in the directines z and ρ

$$\frac{d\varphi}{dz}=\frac{R^3}{2}\left\{\frac{3z^2}{r^5}-\frac{1}{r^3}\right\}-1$$

$$\frac{d\varphi}{d\rho}=\frac{R^3}{2}\,\frac{3\rho z}{r^5}$$

We have from these that the velocity at the points $\rho=o$ and $z=\pm R$ is $=o$. These are the points of intersection of the axis z with the semi-circles. For all points on the semi-circles we have $r=R$, and

$$\frac{d\varphi}{dz}=\frac{3}{2}\left\{\frac{z^2}{R^2}-1\right\}$$

Now $\frac{dz}{dt}$ is the component velocity in the direction of the axis of z, therefore

$$\frac{2}{3}\cdot\frac{dz}{dt}=\left\{\frac{z^2-R^2}{R^2}\right\}$$

Integrating from t_o to t,

$$\tfrac{3}{4}(t-t_o)=\log\frac{R-z}{R+z}$$

If $t_o=o$, we have

$$t=\tfrac{4}{3}\log.\,\frac{R-z}{R+z}.$$

And solving for z

$$z=R\frac{1-\varepsilon^{\frac{3}{4t}}}{1+\varepsilon^{\frac{3}{4t}}}$$

This is the vertical distance traversed by any particle on the semi-circle. For any value of z that differs from R by a finite quantity, the above expression will give a finite value for t; but for particles indefinitely near the points of intersection z and the semi-circles, that is, for $z=\pm R$ we have $t=\pm\infty$. The only admissible values are $z=-R$ and $t=\infty$.

A much more complete investigation of stream lines will be given at a future time—for the present I shall leave the subject—merely referring the reader to Rankine's papers in the Phil. Trans.

RAILS FOR THE PHILADELPHIA AND READING RAILROAD.—The Philadelphia and Reading Coal and Iron Company's mill in Reading is full of work at present, and the contracts on hand will keep it busy until September. This mill has been for some time past puddling cold charcoal iron car wheels, instead of pig iron, for the heads of rails for the Philadelphia and Reading Railroad. This makes a superior rail, at a slight advance in price over an ordinary rail, which is more than repaid by the greater wear.

—*Engineering.*

THE DETERMINATION OF MANGANESE.

ON A NEW VOLUMETRIC METHOD OF DETERMINING MANGANESE IN MANGANIFEROUS IRON ORES, SPIEGELEISEN, STEEL, &c.*

By JOHN PATTINSON, F.I.C.

From "Engineering."

The manufactures of spiegeleisen and ferro-manganese, and the use of these substances in the manufacture of steel, have assumed such large proportions, that an expeditious method of accurately determining manganese in such materials, as well as in manganiferous iron ores, slags, &c., is one of the most urgent requirements in the laboratories of steel and smelting works. The usual gravimetric method of determining this metal is extremely tedious and troublesome. The greater part of two days is very fully occupied by the numerous filtrations, evaporations, ignitions, weighings, and other operations this method requires before the amount of manganese in a manganiferous iron ore, for instance, can be ascertained. The method, moreover, when applied in the usual manner to such ores, and to slags or other substances containing lime or magnesia, is often inexact and uncertain. The precipitate of manganese oxides obtained by adding bromine to an ammoniacal solution containing manganese carries down with it portions of nearly every other substance contained in the solution. It is usual to separate and determine the silica, baryta, zinc oxide ferric oxide, and some other oxides in this precipitate, but it is not usual to separate any lime or magnesia which may also be present, and hence it is that the manganese in these ores, &c., is sometimes much overstated. I have known cases where differences of upwards of 1½ per cent. in the results of different chemists have occurred from this cause in testing manganiferous iron ores. The difficulty of igniting the oxide of manganese precipitated so as to obtain pure manganoso-manganic oxide (Mn_3O_4) is also another fruitful source of error.

The ordinary gravimetric method as applied to spiegeleisen, ferro-manganese and steel, gives very accurate results if the ignition of the manganese precipitate is carefully attended to, and the ferric oxide, which the precipitate usually contains, is separated. But the slowness of the process is a great objection. The determination of manganese in spiegeleisen by the indirect method—that is, estimating the iron, assuming that the substance contains 5 or 6 per cent. of carbon, silicon, &c., and that the remainder consists of manganese–is a very untrustworthy method. I have known instances where the amount of manganese would have been overstated by more than 2 per-cent. had this method of analysis been adopted.

Many volumetric methods of determining manganese have been proposed from time to time by various chemists, but none have hitherto come into general use. In some cases these methods have failed because it has been found that they are as troublesome as the gravimetric method they were intended to supersede; but most have failed owing to the difficulty or imposibility of obtaining the whole of the manganese in a constantly uniform state of oxidation.

After numerous experiments carried on for a long period, I have at last succeeded in working out a method by which the whole of the manganese in a solution may with certainty be precipitated as hydrated dioxide, and the amount of this oxide readily and accurately measured.

I find that the whole of the manganese in a solution of manganous chloride can be invariably precipitated as dioxide, if a certain amount of ferric chloride be also present in the solution when a sufficient excess of solution of calcium hypochlorite (bleaching powder), or bromine water, is added, and, after heating the solution to from 140° to 160° Fah., (60° to 70° Cent.), excess of calcium carbonate is then added, and the mixture well stirred.

When the ferric salt is absent, and the other conditions are observed—that is, when excess of solution of calcium hypochlorite or bromine water is added

* Paper read before the Iron and Steel Institute.

to a solution of pure manganous chloride then, after heating to about 150° Fah. adding excess of calcium carbonate, and stirring—the precipitate invariably contains a certain proportion of lower manganese oxides, the amount of manganese precipitated as dioxide varying from 98.20 to 99.27 per cent. of the amount of manganese present in the solution.

Heat is also essential in order to obtain all the manganese as dioxide, for if the precipitation it made by calcium hypochlorite and calcium carbonate in the presence of much ferric chloride in the cold, the precipitate then contains only from 98 to 99 per cent. of its manganese as dioxide.

I have also experimented carefully to ascertain the amount of ferric chloride necessary to cause the whole of the manganese to be precipitated in the desired condition of dioxide, and I find that if there is at least half as much iron as manganese in the solution it is sufficient. In practice, however, I prefer to have about equal quantities of each metal in solution. A large excess of iron is no disadvantage.

When equal quantities of manganese and iron are present, and the other conditions fulfilled as described, I have found, by numerous experiments, that the whole of the manganese is precipitated as dioxide, the results I have obtained having almost invariably indicated from 99.95 to 100.12 per cent. of the manganese precipitated in this form, when operating on portions of from three to six grains of pure manganoso-manganic oxide.

I will now describe the manner in which I use the above-mentioned reaction for the quantitative determination of manganese, and this will be done best by giving the details of my method in its application to the testing of manganiferous iron ores, spiegeleisen, ferro-manganese, steel, &c., for manganese.

The following are the special solutions and other special re-agents required in the process. These are all in ordinary use in metallurgical laboratories or can be very readily obtained. They are:

1. *Solution of Calcium Hypochlorite (Bleaching Powder).*—The solution I use is made by diffusing in 10,000 grains of water 150 grains of ordinary bleaching powder or chloride of lime containing about 35 per cent. of available chlorine. The clear solution is separated from the insoluble portion by decantation or filtration and bottled for use.

2. *Calcium Carbonate.*—It is desirable that this should be of a light granular pulverulent character, so that it can be readily diffused through the solution, and does not form clots, which fall at once to the bottom of the beaker in which the precipitation takes place. This kind of carbonate of lime can often be had from the dealers in re-agents, but it may be formed when solutions of calcium chloride and sodium carbonate are added together at a temperature of about 180° Fah., keeping the calcium chloride slightly in excess, and washing the precipitate well and drying.

3. *Solution of Ferrous Sulphate in excess of Sulphuric Acid.*—The solution I use contains about 10 grains of iron in 1000 grains of solution, and is made by dissolving crystals of ferrous sulphate in a mixture of one part of monohydrated sulphuric acid and three parts of water; 530 grains of crystals in 10,000 grains of the dilute acid give a solution containing about ten grains of iron in each 1000 grains.

4. *Standard Solution of Potassium Dichromate.*—The solution I use is made so that 1000 grains of it are equal to 10 grains of iron, and is the solution I use in the determination of iron in iron ores, &c. It should be carefully standardized.

Manganiferous Iron Ores.—These ores generally contain from 15 to 25 per cent. of manganese, and at least 20 per cent. of iron. They, therefore, usually contain a sufficient amount of iron for the dioxide precipitation. Ten grains of the ore, dried at 212° Fah., are placed in a beaker of about 20 ozs. capacity, and dissolved, by the aid of heat, in about 100 fluid grains of hydrochloric acid of about 1180 specific gravity. When completely dissolved, the cover and sides of the beaker are rinsed by a jet of cold water, and then calcium carbonate is added until the solution becomes of a slightly reddish color, showing that the free acid is neutralized. Six or seven drops of hydrochloric acid are now added in order to slightly acidify the solution, as it is found that the precipitate falls in the best condition for being filtered and washed when this is done. About 1,000 grains of the

solution of bleaching powder are now added, and then boiling water is run in until the solution is heated to about 140° to 160° Fah. When the right temperature has been reached may be sufficiently nearly ascertained by applying the hand. About 25 grains of calcium carbonate (which, for convenience, may be measured) are now added, and the solution well stirred until the evolution of carbonic acid ceases. The dark brown precipitate of oxides of manganese and iron settles readily, generally leaving a colorless supernatent liquid; but if the bleaching powder has been much in excess, the supernatent liquid has sometimes a pink color owing to the formation of permanganic acid. Should this be the case, a few drops of alcohol are added until the pink color is destroyed. If sufficient bleaching powder has been added, the solution smells of chlorine, or it may be tested for excess by a strip of iodised starch paper.

Instead of the solution of bleaching powder, about 500 grains of saturated bromine water may be used. In this case, it is unnecessary to add any acid after the neutralization of the solution by calcium carbonate, as sufficient acid is formed in the reaction. Care must be taken that sufficient calcium carbonate is present to neutralize all free acid.

The precipitate is now collected on a double filter of sufficient capacity, and washed with cold or warm water until the washings show no trace of chlorine or bromine, when carefully tested by iodised starch paper. The washing is readily accomplished, and rarely takes longer than a quarter of an hour.

A thousand grains of the acidified ferrous sulphate solution are now carefully measured from a pipette into the beaker in which the precipitation has been made, and which usually contains a small quantity of adhering dioxide, and the filter with its contents are removed from the funnel and placed in the iron solution. The precipitate very readily dissolves, even in the cold solution, the manganese dioxide converting its equivalent of ferrous sulphate into ferric sulphate. A sufficient amount of cold water is now added, and the amount of ferrous sulphate still remaining in the solution is ascertained, by adding from a burette the standard solution of potassium dichromate, just as in the testing of an iron ore.

The exact amount of ferrous sulphate existing in the 1000 grains of ferrous sulphate solution at first is determined by measuring another 1000 grains from the pipette, and after adding a filter to it of the size used in collecting and washing the precipitate, titrating it with the potassium dichromate solution. Sometimes filtering paper has a slightly reducing action, and the influence of this is thus counteracted. It is, however, quite easy to obtain filtering paper that has no reducing action on the solution; but it is safer to standardise after adding a filter to the solution as I have directed.

Supposing the 1000 grains of ferrous sulphate solution used in standardizing has required 101.1° of dichromate solution (I use a burette graduated to hold 150° of 10 grains each, or 1500 grains), and the 1000 grains to which the manganese precipitate obtained in testing an ore has been added has required 57.0° of the dichromate solution, the percentage of manganese in the ore is calculated as follows: 101.1−57.0=44.1° of dichromate solution, which are equal to 4.41 grains of iron, the amount of iron converted from ferrous to ferric sulphate by the manganese dioxide yielded by 10 grains of the ore. On multiplying the amount of iron thus peroxidized by 0.491 the total amount of manganese contained in the ore is ascertained. In this case, $4.41 \times 0.491 = 2.165$ grains of manganese in the 10 grains of ore, equal to 21.65 per cent.

Should the ore to be tested be a rich manganese ore, containing less iron than one-half the manganese it contains, it will then be necessary to add a sufficient amount of ferric chloride free from manganese. As before mentioned, I prefer having about equal parts of manganese and iron when the precipitation is made. The ferric chloride I use for this purpose, and which was used in the above-mentioned experiments with pure Mn_2O_3, is prepared by precipitating the ferric oxide in a ferric salt once or twice with calcium carbonate, and washing so as to get rid of the small amount of manganese which even the purest iron wire contains. The ferric oxide is then dissolved in hydrochloric acid, and made up to a known bulk.

For the amounts of bleaching powder

solution, and other re-agents mentioned above, it will be necessary to operate upon such a quantity of the sample as will not contain much more than about 2.5 grains of manganese. If larger quantities are taken, then the amounts of the re-agents must also be proportionately increased. But it is unnecessary to operate upon a larger quantity than I have indicated, seeing that there is no difficulty in obtaining results which agree within a tenth of a per cent.; moreover, the bulk of the precipitate from such a quantity, and the amounts of solutions required, are convenient to work with.

If it is preferred, a larger quantity of the ore—say 50 or 100 grains—may be dissolved, and the solution made up to a known bulk in a measuring flask, from which measured portions may be taken.

It is necessary to standarise the ferrous sulphate solution about once a day, as it becomes slowly oxidized on exposure to air.

Spiegeleisen.—This alloy usually contains from10 to 25 per cent. of manganese, and, of course, a sufficient amount of iron for the dioxide precipitation. Ten grains are taken for analysis. This amount is dissolved in about 120 grains of hydrochloric acid with the aid of heat. About 50 grains of nitric acid are then added for the purpose of converting the ferrous into ferric chloride. After washing the cover and sides of the beaker with cold water, the excess of acid is neutralized by the addition of calcium carbonate until the solution has a reddish color; 1000 grains of the bleaching powder solution or about 500 grains of bromine water are added, without previous addition of hydrochloric acid as in the case of ores. Hot water is then added to heat the solution to from 140 deg. to 160 deg. Fahr., and then about 25 grains of calcium carbonate; and the solution well stirred. The rest of the process is conducted as before described.

Ferro-Manganese.—For the quantitative analysis of the alloy an amount which contains from 2 to 4 grains of manganese may be taken. The solution is made as in the case of spiegeleisen. If the alloy contains less iron than manganese ferric chloride is added so as to make the amounts of the two metals in the solution about equal.*

The amount of bleaching powder solution to be added must depend upon the amount of manganese in the solution, taking care to add about 400 grains of bleaching powder solution of the stregth above named for every grain of manganese present.

As in the case of ores, instead of weighing off separately the amounts required for each test, a larger quantity may be dissolved and peroxidized, and after making up the solution to a known bulk in a measuring flask, the necessary quantities for the tests measured out.

Steel.—Fifty grains of steel are dissolved, by the acid of heat, in about 350 grains of hydrochloric acid of about 1180 specific gravity. The iron is then converted into ferric chloride by the addition of about 90 grains of nitric acid of about 1440 specific gravity. The solution is made in a beaker of about 30 ozs. capacity. Calcium carbonate is then added until the solution is slightly red; 135 grains of calcium carbonate are now weighed or measured, and about one-half of this added to the solution. After the effervescence caused by the escape of carbonic gas has ceased, about 400 grains of the bleaching powder solution are added, and then hot water to heat about 150 deg. Fahr., and then the remainder of the calcium carbonate. If all the calcium carbonate is added at once, the effervescence is so great that the substance is likely to froth over the edges of the vessel; and if the bleaching powder solution is added before any calcium carbonate has been added, the chlorine is likely to be expelled by the evolution of the carbonic acid. The calcium carbonate is, therefore, added at twice, and the bleaching powder solution between the two additions. The precipitate is then thrown on a sufficiently large filter and washed until free from any trace of chlorine. Although the precipitate is bulky it is very readily washed.

* Since the above was written I have ascertained that F. Kessler recommends the use of zinc chloride for the purpose of preventing the formation of lower oxides than dioxide when manganese is precipitated from its solutions (Zeitschr. Anal. Chem., 1877, 1-14). The method by which he proposes to utilize this reaction for the volumetric analysis of manganese is, in my opinion, too troublesome and complicated for ordinary use; but I have tried the use of zinc chloride instead of ferric chloride as applied to my method of precipitation and analysis, and find it answers equally well, and that it is sufficent to have about as much zinc as manganese present in solution. In cases, therefore, where a sufficient amount of iron is not already present. An addition of zinc chloride may be substituted for the ferric chloride above recommended.

About 200 grains of the ferrous sulphate solution are standardised, and the same quantity used for decomposing the manganese dioxide in the case of steels; but it is sometimes found necessary to add a little additional sulphuric acid in order to dissolve the ferric oxide precipitate and the excess of calcium carbonate it may contain.

Manganese Slags, &c.—These are treated similarly to the above, using for the analysis such a quantity as will not contain more than about 2.5 grains of manganese for the above amounts of re-agents, and taking care to have a sufficient amount of ferric chloride in the solution when the manganese is precipitated.

Should lead, copper, nickel, or cobalt exist in the substance under examination, these must be separated before the manganese is precipitated, as they form higher oxides under the conditions of the precipitations, which oxides, like manganese dioxide, convert ferrous into ferric oxide. Fortunately, in most manganiferous iron ores, and in spiegeleisen, ferro-manganese, and steel, none of these metals occur in such quantity as to appreciably affect the correct estimation of the manganese.

In testing spiegeleisen and ferro-manganese, which do not contain lime or magnesia, the results of the direct gravimetric method agree fairly well with those given by the new volumetric method, if, in the gravimetric method, care has been taken to heat the bromine precipitatate to a long-continued high red heat, and to separate the iron it usually contains, the difference between the results of the two methods being seldom more than one-tenth of a per cent. The following are a few of the results I have obtained by both methods of analysis:

	By usual Gravimetric Analysis. per cent.	By new Volumetric Analysis. per cent.
1.	19.81	19.89
	—	19.84
2.	22.41	22.39
	22.46	22.41
3.	28.80	28.92
	28.76	28.92
4.	55 51	55.58
	55.66	55.58
5.	69.34	69.34
	69.34	69.34
6.	74.81	74.93
	74.95	74.93

The new method also answers very well for the determination of manganese in steels. Two portions of 50 grains of pure iron, to which known weights of manganese were added, indicated 0.304 and 0.640 per cent. of manganese instead of 0.302 and 0.604 per cent. respectively. A steel which, by careful gravimetric analysis, was found to contain 0.912 per cent. of manganese indicated 0.92 per cent. by the new volumetric method.

I have tested very large numbers of samples of manganiferous iron ore, spiegeleisen, and ferro-manganese by the method I have described in this paper, and have found that the results of the duplicate tests have been almost invariably alike, there being only occasionally a difference of 0.1 deg. or 0.2 deg. in the reading of the burette, equal to 0.05 or 0.10 per cent. of manganese in the sample. In fact, it is now possible to determine manganes evolumetrically by this method as exactly, and almost as speedily, as it is possible to determine iron volumetrically by Penny's well-known bichromate of potash method.

Transmission of Motive Power.—M. Tresca laid before the French Academy of Sciences, at a recent meeting, some information on this subject. On the Lyons Railway a force of from two to three-horse power had been transmitted to a considerable distance, to work a crane, by means of an electric wire. He stated that only last week he had witnessed other experiments of a similar nature at Sermaize (Marne), but in this case the trials were of a more precise nature, and their object was to plough land by electricity. The apparatus consisted of a steam-engine setting in motion a Gramme machine, producing a voltaic current which, at a distance of 400 meters, acted on two Gramme machines at opposite sides of the field, and from these the windlasses of the steam plough were driven. M. Tresca has not yet been able to determine the cost of this process of ploughing as compared with other systems, but he is about to carry out a series of experiments at the Conservatoire des Arts et Métiers, to determine the question. He is of opinion that the expense will not exceed that of other methods now in use.

LINKAGES.

A KINEMATIC DISCUSSION OF THE DIFFERENT FORMS OF ARTICULATED LINKS WITH ESPECIAL REFERENCE TO PEAUCELLIER'S CELL.

By J. D. C. DE ROOS.

Translated from "Revue Universelle des Mines" for Van Nostrand's Magazine.

II.

The system required for the extraction of the *cube root* is more simple, being a combination of three elements only, as shown in Figure 14.

Since the elements have all the same power C^2 we have; taking $OA = x$;

$$AB = \frac{C^2}{x} \quad OB = OA - AB = \frac{x^2 - C^2}{x}$$

$$BC = \frac{C^2}{OB} = \frac{C^2 x}{x^2 - C^2}$$

$$AC = BC - AB = \frac{C^2}{x(x^2 - C^2)}$$

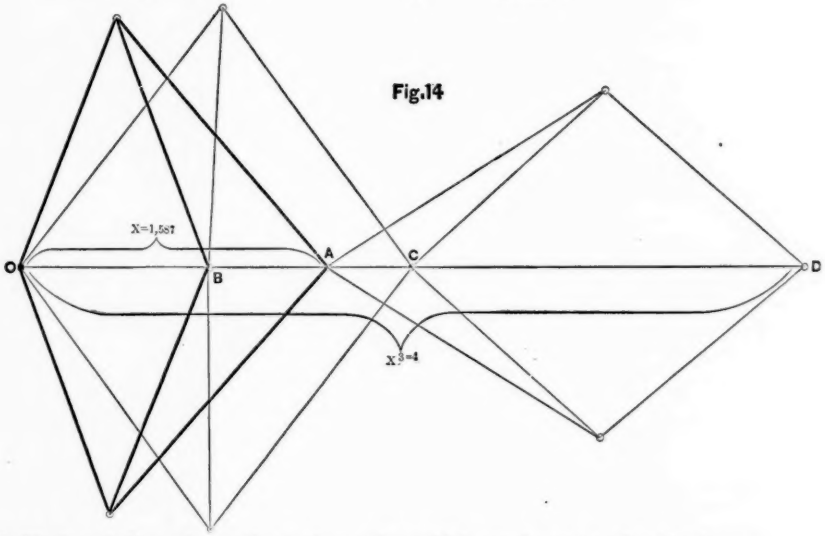
$$AD = \frac{C^2}{AC} = \frac{x(x^2 - C^2)}{C^2} \quad \text{and}$$

$$OD = OA + AD = \frac{x^3}{C^2}$$

then $$\frac{OD}{C} = \left(\frac{x}{C}\right)^3 \text{ or if } C = 1$$

$$OD = x^3.$$

Fig. 14



The resolution of equations of any degree is of more importance than the extraction of roots, and the Peaucellier cell may be applied to these problems in different ways.

Thus, in some cases, the equation can be written in a complex form, the different parts of which may be calculated by means of this linkage.

Take for example the equation

$$4x^3 - 3x - a = 0$$

which can be put under the form

$$a = x - \frac{4C^2}{\frac{C^2}{\frac{C^2}{x} - x} + \frac{C^2}{x}}$$

in which are presented three inversions;

$$\frac{C^2}{x}, \quad \frac{C^2}{\frac{C^2}{x} - x} \quad \text{and} \quad \frac{4C^2}{\frac{C^2}{\frac{C^2}{x} - x} + \frac{C^2}{x}}$$

The solution then requires three elements whose powers are, C^2, C^2 and $(2C)^2$ which we will couple as indicated in Fig. 15.

Now taking $OA = x$, we have

$$AB = \frac{C^2}{x}, \quad OB = AB - OA = \frac{C^2 - x^2}{x},$$

$$CB = \frac{C^2}{OB} = \frac{C^2 x}{C^2 - x^2},$$

$$AC = CB + AB = \frac{C^2}{x(C^2 - x^2)},$$

$$AD = \frac{4C^2}{AC} = \frac{4x(C^2 - x^2)}{C^2}$$

and

$$OD = OA - AD = \frac{4x^3 - 3xC^2}{C^2}$$

then

$$\frac{OD}{C} = 4\left(\frac{x}{C}\right)^3 - 3\left(\frac{x}{C}\right)$$

or expressing OD and x as functions of C;

$$4x^3 - 3x - OD = 0,$$

so that making $OA = x$ gives one of the roots of the equation, taking $OD = a$.

This system will also afford a solution of the famous problem, the *tri-section of an angle.* Since in the trigonometrical expression

$$\cos 3a = 4\cos^3 a + 3\cos a$$

we have $\frac{X}{C} = \cos a$, by taking $\frac{OD}{C} = \cos 3a$

Thus in Fig. 15 we have taken

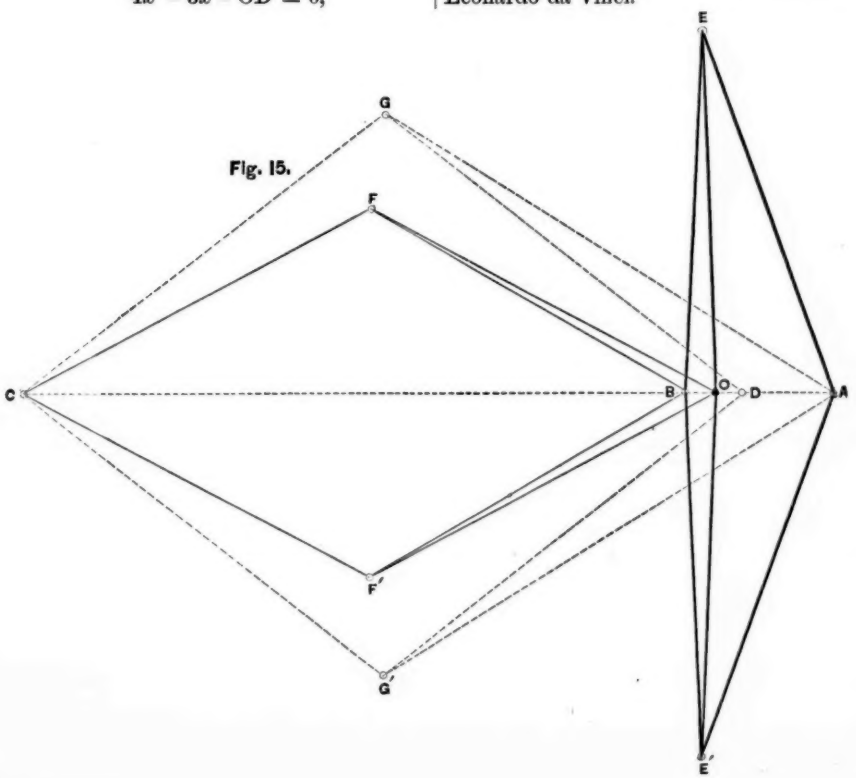
$$OD = 20\cos 75° = 5.176$$

and we find $\cos a = \frac{OA}{C} \cdot \frac{18}{20} = 0.9$

which gives for a a value of 25°.

Besides this solution there is another by means of curves, whose tracing is possible by the Peaucellier cell, and of which we will speak further on. The trimetric curve serves especially for this purpose, and this curve is obtained equally well by the oval mechanism of Leonardo da Vinci.

Fig. 15.



In resolving the equation above we have written it under a more complex form, without concerning ourselves with the question of how far such a reduction is systematically possible, as such a question would be aside from the purpose of this paper, and furthermore, as another and more general method may be followed for the mechanical solution of equations of any degree.

This method which we believe to be new, is based upon the well-known property that in all complete equations arranged with reference to the powers of the unknown quantity, the co-efficient of the second term is equal to the sum of the roots taken with contrary sign; the co-efficient of the third term is equal to the sum of their products taken two and two; and the co-efficient of the fourth term is equal to the sum of the products three and three, taken with the opposite sign, etc., and finally, that the last term is equal to the product of all the roots, taken with the same or the contrary sign, according as the degree of the equation is even or odd.

The general form of an equation of the second degree would thus be:

$$x^2 - (a + b)\, x + ab = 0,$$

supposing for the sake of simplicity, that the roots a and b are real and positive.

Since in a negative Peaucellier element, of which the power $\overline{OB}^2 - \overline{BC}^2$ is ab, (Fig. 16) the product of the arms OB and BA remains in all possible positions of the system constant and equal to ab; it follows that the different values of OB and BA give all possible cases of the constant product ab, and of all these values it is necessary only that we take the two whose sum is $a+b$, we have only to make $OA = a + b$. This is easily accomplished by a divided scale along OA, and the roots are then immediately given by OB and BA.

For the different values of the product of the roots, the hinges C and C′ can be adjustable as in the proportional dividers, or quite as well, and what is more simple, the product of the roots can be reduced to the constant value $\overline{OC}^2 - \overline{CB}^2$ by multiplying by n, which changes the equation to

$$x_1^2 - n\,(a+b)\, x_1 + n_2\, ab = 0$$

in which n can be chosen so that

$$\overline{OC}^2 - \overline{BC}^2 = n^2\, ab.$$

For the case where the two roots are negative the signs may be changed, and if one only is positive or negative, the solution requires a positive Peaucellier element instead of a negative one.

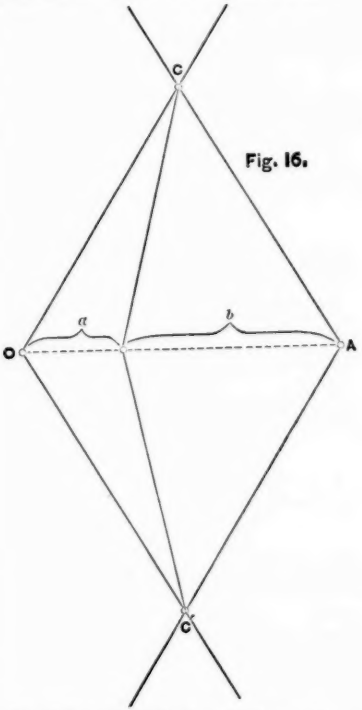


Fig. 16.

In the mechanical solutions of equations of higher degrees it happens that some of the distances or lengths require to be transposed. The combination of links which effects this is designated the *transporter*, and is constructed as indicated in Fig. 17.

This arrangement is not the most simple; it can be replaced by the isosceles figure with crossed sides shown in Fig. 44. We prefer, however, to apply here the system of six rods as in Fig. 17 by reason of the symmetry.

In this arrangement the bars form two lozenges, one within the other, in such a manner that OB=O′B′, or in other terms, OB is always transported in O′B′.

The general equation of the third degree

$x^3-(a+b+c)x^2+(ab+ac+bc)+x-abc=o$ in which, for the sake of simplicity, we suppose the roots a, b and c, to be real and positive; is solved mechanically by aid of a transporter and three negative Peaucellier elements (Fig. 18) of which the powers $\overline{OF}^2-\overline{FB}^2$, $\overline{O'C}^2-\overline{BG}^2$ and $\overline{DH}^2-\overline{EH}^2$ are equal among themselves, and to abc or to n^3abc if we make the roots n times as great.

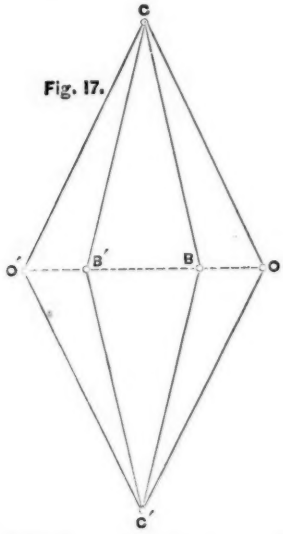


Fig. 17.

For this purpose it is only necessary to move A, in the direction of O and A', towards O', so that OA shall be equal to $ac+bc+ab$ or to $n^2(ac+bc+ab)$ and so that $O'A'=a+b+c$ or to $n(a+b+c)$; the distances O'B, BC and CA' giving then immediately the values of the roots directly, or these values multiplied by n.

The values are represented as follows:

$$O'B=a \quad BC=b \text{ and } CA'=c$$

$$O'A'=a+b+c$$

and $$OB=\frac{OF^2-FB^2}{BC}=\frac{abc}{b}=ac$$

$$BE=\frac{abc}{a}=bc$$

since $$EA=\frac{abc}{DE}=\frac{abc}{CA'}=ab$$

then $$OA=ac+bc+ab$$

It follows inversely that O'B, BC and CA' will represent the roots of the equation if O'A' is equal to the coefficient of the 2nd term, and OA to that of the 3rd term.

It is understood that the connection of the elements is such that their arms remain constantly upon the line OA. In the present instance this condition is verified only for the two elements II' and HH' while the arm of the element GG' coincides with a line passing through E, and the arm of the system FF' with all lines passing through C; consequently the three points B, C and A form in general a triangle instead of being situated in a right line.

It is easy to obviate this by making the points to move in a groove; then the lower half of the system may be dispensed with, and the working simplified. In every case it would be necessary to employ a divided scale with the groove, in order to be able to fix the points O, A, O' and A' at determined distances in order to read off the values of a, b and c.

For our present purpose, however, it is more in keeping to employ the articulated rods only.

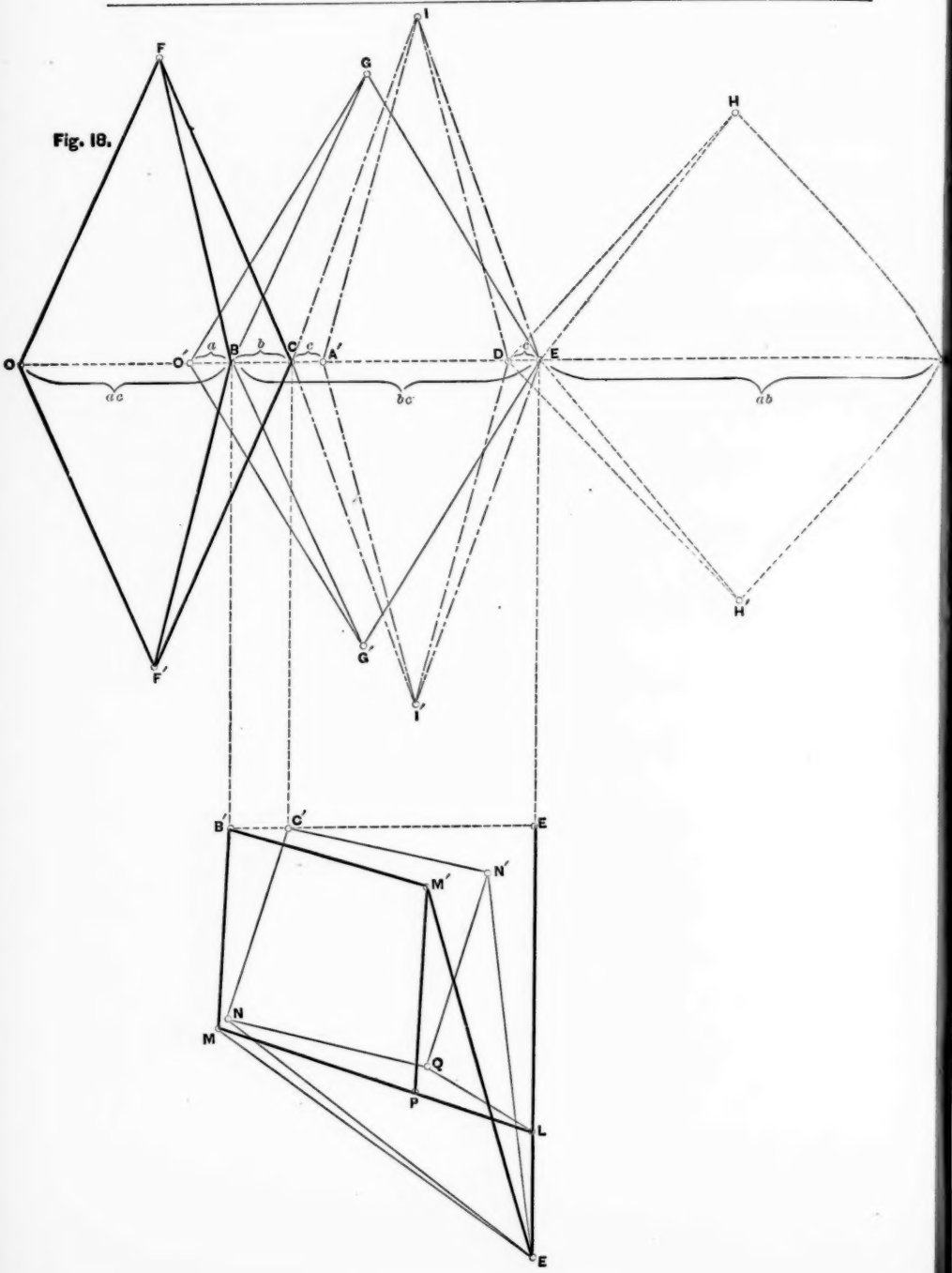
It is clear that it will suffice to guide a single point such as C, in the direction passing through two other points B and E, which, by reason of the reciprocal connection of the four elements, are not forced to move in line with C; and consequently the conditions require that C be guided to move alone a line of variable length as BE.

This is easily accomplished in different ways: for example; by coupling the points B', C and E' of the two systems KLB' and KLC' (Fig. 18) respectively to the points B, C and E.

Each of the systems has eight links, being formed of a *reciprocator* KPB' of Peaucellier, and two rods of equal length KL and LP; but as they have the link KL common, the two systems form together a combination of fifteen links.

The elements of these compound systems are called *protracteurs* or *retracteurs*, and we shall see further on (in Figs. 24 and 25) that they enjoy the remarkable property that B' and similarly C' can move along the line B'E' perpendicular to KL. This line passes invariably through the point E' situated on KL or its prolongation; this being the geometrical place of B' or C' at the

Fig. 18.



moment that PL or QL coincides with the prolongation of KL. So that although the distance of either B′ or C′ from E′ may change value, the two points are forced to follow the right line passing through E′.

We will not now consider the cases of imaginary roots; this subject requires separate treatment. But we have no doubt that the solutions of higher equations, by means of linkages, will be preferred to the graphical solutions of Lill, as explained in the work of Dr. Luigi Cremona. (Elements der Graphischen Calculs: Leipsig 1875).

Furthermore, we believe that the solutions explained above are capable of being to a considerable extent simplified, and that it is possible to discover analogous combinations for solutions of equations of higher orders.

The examples given will suffice to show how the Peaucellier cell may be used as an instrument for calculation.

It is true that some solutions require complex combinations, and so are only interesting from a theoretical point of view, but it is not impossible to bring about a simplification analogous to that which transforms the Peaucellier cell into a pantagraph.

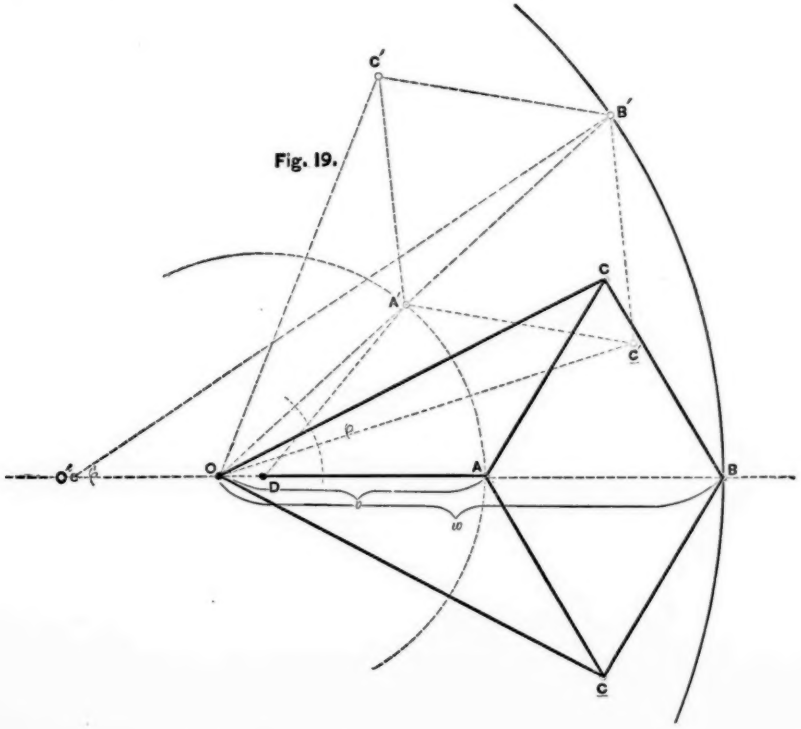
It seems then that linkages promise to render some day excellent service as instruments for calculation, just as the Peaucellier cell has already proved serviceable as an instrument for drawing.

It is this latter property that we propose to study in the following chapter.

THE PEAUCELLIER CELL AS A DRAWING INSTRUMENT.

By placing the pole A of the positive system OCBC (Fig. 19) at the center D in such a manner as to cause it to describe an arc of a circle AA′, and maintaining the point O in a fixed position (a condition indicated in the diagram by the black circles at O and D) the point B will be found upon a curve BB′ whose equation is readily found.

Fig. 19.



Putting $OA=v$, $OB=w$, $OB'=z$, $AD=A'D=r$, and the angle $A'OD=\varphi$

We shall have

$$r^2=(v-r)^2+\overline{OA'}^2-2(v-r)OA'\cos.\varphi$$

whence

$$OA'=(v-r)\cos\varphi\pm\sqrt{r^2-(v-r)^2\sin^2\varphi}$$

and since

$$C^2=vw=OA'z,$$

$$z=\frac{vw}{(v-r)\cos\varphi\pm\sqrt{[r^2-(v-r)^2\sin^2\varphi]}}=$$

$$=\frac{w}{v-2r}\left\{(v-r)\cos\varphi\mp\sqrt{[r^2-(v-r^2\sin^2\varphi]}\right\},$$

an expression both of whose signs are applicable.

It is the equation of a circle whose radius is R, and since for

$$\left(\varphi=0,\ z=w \text{ or } \frac{wv}{v-2r}\right.$$

and for

$$\left.\varphi=180,\ z=-\frac{wv}{v-2r} \text{ or } -w\right)$$

it is clear that

$$R=\frac{1}{2}\left\{w+\left(-\frac{wv}{v-2r}\right)\right\}=\frac{1}{2}\left\{\frac{vw}{v-2r}+(-w)\right\}$$

then in general

$$R=\mp\frac{wr}{v-2r}.$$

By transposing the origin of a quantity:

$OO'=\mp\frac{wr}{v-2r}-w$ we shall have $O'B'=z'$

$$=\sqrt{z^2+\overline{OO'}^2+2zOO'\cos\varphi}=\text{a constant}=\mp\frac{wr}{v-2r}$$

From this value of R we readily get

$$r=\frac{vR}{2R\mp w}$$

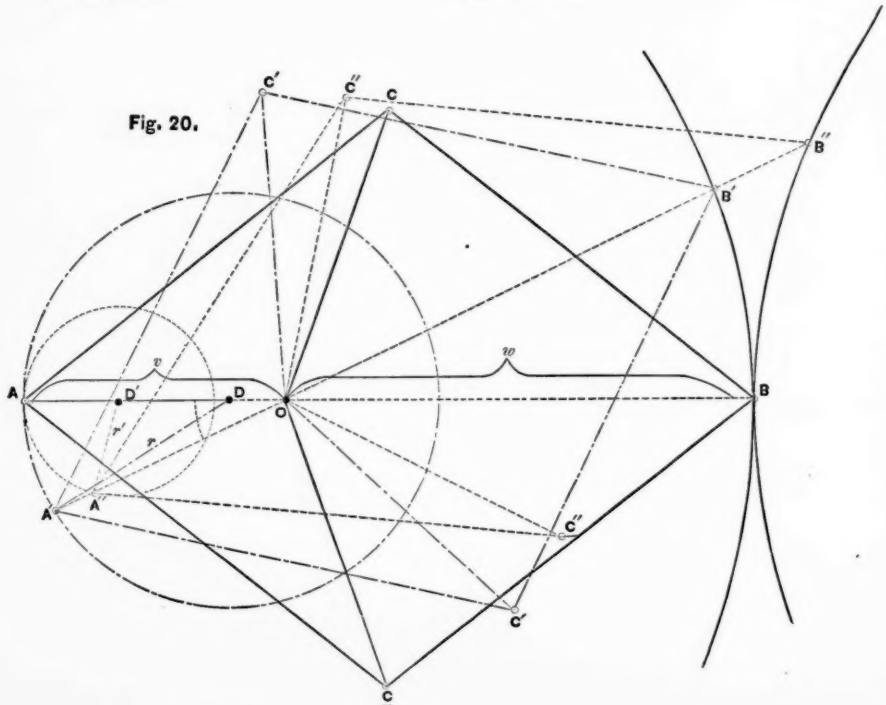
so that we can trace an arc of given radius R by employing two different radii.

The position of the circle however will not be the same for the two cases which result from the double value

$$OO'=\mp\frac{wr}{v-2r}-w$$

or again from the two values $-R-w$ and $+R-w$.

Fig. 20.



In the negative system (Fig. 20) OA′, OB′ and also R preserve the same values as in the positive system, for the same values of v, w, r and φ.

The space occupied by the instrument is greater in case of (Fig. 20) than in that of (Fig. 19.)

The figure shows two arcs of circles, tangent to each other, having the same radius R traced by the two values of r (AD and AD′).

These circumferences approach each other as R increases and coincide when $v=2r$ or $R=\infty$.

For this value B describes a perpendicular to AB passing through B.

It is understood that the systems of figures 19 and 20 can assume a symmetrical position, that is to say, a position in which the center D is found upon the diagonal of the lozenge or upon its prolongation which passes through O.

But such position is not always possible, especially when r is large compared to v and w.

Nevertheless the formulas preserve their applicability, inasmuch as v and w are in all cases theoretically determinable.

Instruments for describing arcs of circles of great radius, are now found for sale under the name of compound compasses (*compas composé*) and although of relatively small dimensions will describe arcs of any radius.

Sylvester's Linkage described above affords equally a practical means of drawing arcs of large radius.

In Fig. 21 if the point O be fixed and the point A be made to describe a circle passing through O about the center D, the point B will also describe the arc of a circle.

For by equation 3 we have, giving the letters the same signification:

$$OA.'OB'-\left(1-\frac{n'}{n}\right)OB'^2=\frac{n'}{n}C^2.$$

whence

$$OB'=y=-\frac{1}{2}\frac{nOA'}{n'-n}\pm\sqrt{\left\{\frac{n'C^2}{n'-n}+\frac{1}{4}\frac{n^2OA'^2}{(n'-n)^2}\right\}}$$

and because

$$OA'=2A'D\cos(A'OD)=2r\cos\varphi,$$

$$y=-\frac{n}{n'-n}r\cos\varphi\pm\sqrt{\left\{\frac{n'C^2}{n'-n}+\frac{n^2r^2\cos^2\varphi}{(n'-n)^2}\right\}}$$

This is the equation of a circle whose radius

$$R=\pm\frac{1}{n'-n}\sqrt{[n'(n'-n)C^2+n^2r^2]}.$$

Replacing C^2 by the value OB, the radical disappears, since

$$OA.OB-\left(1-\frac{n'}{n}\right)OB^2=\frac{n'}{n}C^2 \text{ and } OA=2r$$

then $$C^2=2r\frac{n}{n'}OB+\frac{n'-n}{n'}OB^2$$

and consequently

$$R=\pm\left(OB+\frac{nr}{n'-n}\right)$$

and also $$\frac{n'}{n}=1+\frac{r}{-OB\pm R}.$$

In this expression the two signs indicate simply curvature in opposite directions. For $n=n'$ the radius becomes infinite as in the case of the Peaucellier instrument, and the arc BB′ becomes a straight line perpendicular to OB at B.

This remarkable property is now applied in mechanism for the conversion of alternate circular into perfect rectilinear motion.

This device is an improvement upon Watt's "parallel motion," although more complicated, because it is strictly exact.

Instead of describing a perpendicular to the line OD, it is equally possible to trace a parallel to it. This, however, requires a more complex combination. It is made up of two ordinary elements and two of the *system varié* of Peaucellier, all of the same power, and united as shown in Fig. 22.

We have in this case

$$OH=\frac{C^2}{OA},$$

$$\overline{OI}^2=\overline{OH}^2-C^2=\frac{C^2(C^2-\overline{OA}^2)}{\overline{OA}^2}$$

$$OF=\frac{C^2}{OI}=\frac{C.\,OA}{\sqrt{C^2-OA^2}}$$

and $$\overline{OB}^2=C^2+\overline{OF}^2$$

or $$OB=\sqrt{\frac{C^4}{C^2-\overline{OA}^2}}$$

Giving O a fixed position, and describing with A, a circle pssing through O, having a radius $r=OD=AD$, and calling the angle $AOD=\varphi$, we shall have

$$OA=2r\cos\varphi$$

and consequently,

$$OB=\frac{C^2}{\sqrt{C^2-4r^2\cos^2\varphi}}$$

or making $C^2=4r^2$

$$OB=\frac{2r}{\sin\varphi}$$

Consequently the point B will describe a right line parallel to OD at a distance of $2r$ from it.

PONSARD'S FORNOCONVERTISSEUR FOR THE MANUFACTURE OF STEEL.

By J. SYLVAIN PÉRISSÉ, Member of the International Jury, Paris.

Journal of the Iron and Steel Institute.

All metallurgists are conversant with the two principal processes by means of which steel is manufactured on a large scale.

The Bessemer and Martin-Siemens processes now supply almost the whole of the cast metal which tends more and more to replace iron; and it may be sufficient to state here that all the railway companies have almost exclusively adopted steel rails, and that the general tendency is to use steel or cast metal for the manufacture of plates for boilers and various metallic constructions, and also of wrought pieces for ordnance and machinery.

Let us cursorily examine the principal points which characterize both processes.

Mr. Bessemer's admirable invention, which has brought about a veritable revolution in the metallurgy of iron, is based upon the refining of cast iron by intermolecular combustion, by means of a current of air blown through the molten metallic mass. The heat evolved by this intermolecular combustion must be sufficient to raise the metal to, and maintain it at, a very high temperature without having recourse to any external source of heat. The result is a cast iron which they term "hot," and which contains more or less silicon, according to the proportion of manganese that accompanies it. Indeed, it is known that the combustion of silicon by the oxygen of the air evolves a much greater quantity of heat than carbon, and that cast iron containing less than two per cent. of that element can be used with certainty of success in the Bessemer converter—only on condition that it contains several hundredths of manganese, the heating power of which in that operation appears to be sufficiently high in comparison with that of carbon.

I may add that a specimen of Bessemer's cast iron now has in the average one of the following compositions:—

	Containing manganese.	Containing no manganese.
Silicon....	2.0	3.0 to 4 per cent.
Manganese	2.0 to 4	— "
Carbon....	3.5 to 4	3.5 to 4 "

The proportion approximates more the higher figure when the final addition of spiegeleisen does not take place.

The Bessemer operation requires, therefore, special kinds of cast iron, even if we do not consider the question of purity, and in order to obtain them in the blast furnace it is necessary to keep the apparatus at a high temperature. This is now easy, thanks to the powerful hot blast apparatus of Cowper or Whitwell, which is used for the Bessemer cast iron.

The manufacture of steel by the Bessemer system possesses many advantages. The operation is in itself very economical, more economical even than the ordinary process for the manufacture of iron, but one must not lose sight of the fact that this result is obtained only with a very large production and a highly expensive plant.

In the Martin-Siemens process, steel is produced in quite a different manner, which most generally consists in dissolving in a bath of molten cast iron upon the hearth of a gas furnace a more or less large proportion of malleable metal. It is no longer necessary to use a special hot cast iron, as in the Bessemer process, since the bath is in an atmosphere of a

high temperature. It is even better to have at one's disposal cast iron containing less foreign substances, and a strong proportion of silicon would become even hurtful.

In this process of manufacture small trial-ingots are taken before the close of the operation, to make sure that the metal possesses the requisite qualities, according to the uses for which it is intended; and by final additions it becomes easy to arrive at the required degree of malleability. This possibility of modifying at will the nature of the metal does not exist in the same degree in Bessemer's process. That is the principal advantage of the system of manufacture on hearth. Moreover, one may use a large quantity of old steel, or of waste steel arising from the manufacture, and one can easily understand that such a quantity may be three or four times greater than the weight of the cast iron, since, strictly speaking, Siemens' furnace might be only and entirely charged with bits of rails and other waste or old steel, which would melt under the influence of the high temperature evolved in those furnaces.

The proportion of waste or old steel in the manufacture of rails, for instance, is relatively considerable. In a great number of cases where steel is manufactured by the Bessemer process, they throw into the furnace a proportion of waste or old steel, but then they are obliged to use cast iron containing more silicon, and the conditions are little favorable to the certain success of the operation. Thus the Martin-Siemens process supplements that of the Bessemer in the utilization of old rails and other waste. When, on the contrary, a steel-works has not at its disposal a sufficient quantity of waste or old steel, either because it is wholly organized with the hearth process, or through any other cause, the Martin-Siemens process is not economical, for it requires the use of such a large proportion of iron of such a quality that its price is higher than that of the cast iron operated upon. If that proportion of iron were too greatly reduced, the operation would be a long one, since there is no possibility, as in the Bessemer process, of a rapid refining of the cast iron.

It is, nevertheless, right to add, that several steel-making establishments working with Siemens furnaces use, not without some success, additions of rich and pure ores to hasten the operation, and thus render it more economical; but in such a case we meet with difficulties brought about by the deterioration of the hearth.

By the two principal processes which have just been reviewed, the purification of the metal is not effected; for the whole of the phosphorus contained in the original charge is found also in the resulting product. Now, if we consider that two-thousandths of phosphorus must not be sensibly exceeded, even in a steel which contains sufficient manganese and but little carbon, we must come to the conclusion that the cast iron and malleable iron used in both processes of manufacture must be obtained from the purest ores.

The new furnace proposed by Mr. Ponsard, and to which he has given the name of a Fornoconvertisseur, appears calculated to supply advantages unknown to the two foregoing systems, and to avoid certain drawbacks which have been pointed out in each of them.

The apparatus is composed of a gas furnace heated to a high temperature, the movable hearth of which is supplied with a series of tuyères, and is so disposed as to enable one, during part of the operation, to work by both blast and intermolecular combustion as in the Bessemer system, while maintaining the bath or molten mass under the influence of the high temperature produced by the external source of heat.

The blast is stopped by a partial rotation of the apparatus, which causes the tuyères to be disconnected from the molten metal, and the process is now carried on under the same conditions as the ordinary process of manufacture on the hearth.

It is, therefore, a mixed process that Mr. Ponsard proposes to use—that is, either a disposition of the Bessemer heated furnace, or a gas furnace supplied with the intermolecular blast.

In this direction trials had formerly been made, and dispositions pointed out; but success had not crowned the expectations of the inventors.

At first Mr. Bessemer proposed the use of a retort, heated externally by a fireplace, and in which air or steam was

introduced by a tube dipping in the molten metal.

Subsequently, Mr. Galy-Cazalat used an injection of steam through the metal in a state of fusion in a cylindrical furnace with several tuyères, or in an ordinary reverberatory furnace. The failure of this process, which is analogous with those of Guest and of Nasmith for puddling, was chiefly attributable to the cooling of the bath, which was not compensated for by the energetic heat of a gas furnace.

Afterwards Mr. Bérard made some experiments with his process, which consisted of two furnaces joined together, heated by gas, and provided with movable tubes dipping in the molten metal. The latter was, in turn, submitted to the action of a blast upon one of the hearths, and to that of heated coal gas on the other hearth. Mr. Bérard oxydized and heated the bath by the blast of air, while he hoped to remove both the sulphur and the phosphorus by means of the hydrocarbons.

Later still, Mr. Ponsard made a large hollow poker, kept cool by a current of water, and placed in communication with a powerful blower, by means of which he stirred the metal in the molten iron by blowing into it the air and various re-agents, which effect the refining of the metal. A process, analogous to the foregoing, was afterwards proposed by Mr. Bouiniard for an air-injector, composed of a hollow tube, the lower part of which, having a helicoid shape, gave to the molten metal a movement of rotation.

And lastly, and quite recently—in January, 1878—Mr. Krupp took out in France a patent for an apparatus analogous to Ponsard's Fornoconvertisseur.

To effect the purpose which Mr. Ponsard had in view, he gave two forms to his apparatus. In one of these it has the shape of a barrel, able to move round its horizontal axis, having some analogy with the Danks' furnace, or with the Siemens, Sellers and Crampton's rotators.

The other arrangement, which has been preferred hitherto, has been in course of experimentation, since the early part of the present year, in Messrs. Blondiaux & Co.'s ironworks at Thy-le-Chateau, in Belgium. It consists of a gas furnace, the hearth of which is circular, movable, and inclined, as in Pernot's furnace, and can undergo half a revolution round an oblique axis. Upon one of the points of the circumference of the hearth there is an air-box in communication with the blowing apparatus through the very axis of rotation.

When the hearth is so placed that the tuyères are in the lowest part, the blast acts directly on the metallurgical bath, and the refining is effected as in the Bessemer converter. At the moment when it is thought the amount of carbon in the metal is sufficiently reduced, the hearth is made to rotate round half its axis and the tuyères reach their highest point, so that they emerge from the molten mass, and the metal is no longer under the influence of the current of air, which is automatically stopped by the very motion of the rotating hearth. Small trial ingots may now be taken, as in the Martin-Siemens process, and additions may be made to modify the nature of the metal, without any fear of its cooling, since it is heated by the flame of the gas furnace. Let me add, that if a second air-blast is necessary, it is easy to obtain it by half a revolution of the apparatus. The hearth of the furnace is borne upon a revolving chariot, so that it may easily be repaired or replaced.

Ponsard's Fornoconvertisseur requires to be used at a very high temperature, such as is obtained in Siemens' furnace provided with double regenerators, or in Ponsard's furnace with a single recuperator. It is this latter heating which has been used at Thy-le-Chateau, and I am now about to state briefly the features which characterize it.

Ponsard's furnace has a contiguous gas-holder, and the combustible gases are consumed at the temperature at which they are produced without having suffered any cooling. The products of combustion go into the recuperator which constitutes a hot-air apparatus, destined only to heat the air used for the combustion of gas.

Ponsard's recuperator consists of hollow or solid fire-bricks, and forms an apparatus in which the heating is methodical and without inversion. The burnt gases issuing from the furnace descend into the compartments of the recuperator intended for their reception, whilst the

air ascends in an inverse direction into other parallel compartments, being gradually heated meanwhile. Each vertical air-chamber is always comprised between two "fumies" and reciprocally. The partitions are held together by bricks, most of them hollow, forming "chicanes" upon different courses of the height. Those "chicanes" are intended to present a large surface to the fluids, and, moreover, they establish among the different chambers communications which still further increase the heating surface. It is worthy of notice that those bricks are in juxtaposition, *i.e.*, never placed end to end, so that the recuperator makes allowance for expansion and contraction without any danger of dislocation. The results of a long practice have enabled me to state that Ponsard's recuperator does not get out of shape, and that the lightness of the joints of the bricks is maintained after the recuperator had been cooled and heated a great many times.

In order to make the vertical joints perfectly tight, each "chicane" brick has at the points of junction a groove of 30 millimeters (1.181 inch) by 4 millimeters (0.157 inch); in this manner—by placing two bricks one against the other, they leave an empty space between them, which the mortar fills up, forming a kind of binding which makes the joint tight, because mortar swells when heated, and the bricks cannot be separated when they are placed in juxtaposition and maintained by the sides of the chamber. When, in consequence of long use, the recuperator shows any signs of deterioration, there is no other inconvenience beyond the necessity of replacing an apparatus composed of from six to eight tons of bricks.

Ponsard's recuperator has the double advantage of great power and small volume. The air-heating surface is about 10 square meters (107 square feet) for every cubic meter (35.31 cubic feet), and the weight of a cubic meter is from 800 to 900 kilogrammes (about 15 cwts. 3 qrs. to 17 cwts. 3 qrs.). It thus enables us to heat the air to a temperature varying from 900° to 1050° C. (1620° to 1890° F.) in the numerous metallurgical furnaces to which it is applied.

It should be noticed that the products of combustion issuing from the recuperator are much hotter than those which come out of Siemens' regenerators, since they have only to warm the air required for the combustion of gas. They can, therefore, be still further utilized for the production of steam. In a certain number of soldering furnaces on Ponsard's system, a boiler has been placed next to the recuperator, and it converts into steam 2 kilogrammes (4.4 lbs.) and more of steam for every kilogramme of coal burnt in the gas generator.

I will now state a few of the results of the experiments made at Thy-le-Chateau. The Fornoconvertisseur is in communication with the blowing apparatus of the furnace, which supplies the air at a pressure of from 20 to 21 centimeters (7.87 to 8.264 inch) of mercury, and to arrive at that pressure it is necessary to slacken the blowing of the furnace. The tuyères which have been preferred till now are two of the Bessemer pattern, having 7 holes of 15 millimeters (0.59 inch), which may be used for either 2 or 3 operations. A complete experiment could not be made to determine this point, because the apparatus experimented upon was not used continuously. The duration of the blast varied with the nature of the charge from 20 to 40 minutes.

The charge hitherto has hardly exceeded 5 tons, although the apparatus can work a larger quantity of material; but it must be observed that the pressure of the blast would be insufficient for a greater charge. The operations differed in duration, as always happens in trials of a new apparatus which is still in course of provisional and defective adoption. The average duration was from 5 to 6 hours; but it must be observed that the cast iron was put in cold, and then melted on the hearth of the furnace. The steel waste and bits of iron were heated in an accessory chamber by the waste flames, before their entrance into the recuperator. It would appear from the results obtained by this experience that, by charging the cast iron in the fluid state, and having a spare hearth, 6 to 8 operations could be made every 24 hours; whereas, with the other apparatus used, the number of operations is as follows:—

	operations.
With Siemens-Martin furnaces.....	2 to 3
" Pernot's furnace.....	3 to 4
" Bessemer's converter (very variable)	10 to 20

The gas generator is fed with coal obtained at Mons, 250 kilograms being consumed per hour. The metals hitherto used have been Cumberland cast iron, containing 3 per cent. of silicon, old steel rails, and puddled iron from the phosphorus cast iron of the district.*

The charges were made with various compositions. At first they embraced about one-half cast iron and one-half old rails, and we obtained a fine soft steel, thanks to the high temperature evolved and the use of ferromanganese rich to the extent of 70 per cent. This steel, samples of which are shown in the Universal Exhibition (Large French Machine Gallery, Class 50), has on analysis shown the following composition:

Carbon.....	19	ten-thousandths.
Manganese.....	32	"
Phosphorus.....	6	"

Several experiments were afterwards made with an average composition of one-third cast iron, one-third old rails, and one-third puddled iron, containing 4½ thousandths of phosphorus. Under those conditions the steel obtained contained 23 ten-thousandths of carbon, and 21 ten-thousandths of phosphorus. The phosphorus, therefore, was not eliminated, nor could it be expected that it would be, since the operation was performed, as in the Bessemer and Martin-Siemens processes, in presence of a silicious flux.

It may not, perhaps, be out of place to briefly examine here some of the efforts made and experiments attempted on various occasions to effect the removal of phosphorus from iron with a view to the manufacture of steel.

The members of the Iron and Steel Institute have still fresh in their memory the interesting communication made at their last meeting by Mr. I. Lowthian Bell, on the separation of phosphorus from cast-iron. Mr. Bell's process consists in mixing in a bath at the lowest possible temperature, the cast iron which has to be rid of its phosphorus with half its own weight of ferrous scoria, or forge dross, or iron ore. The pig iron used in the experiments referred to was a grey quality, No. 3, having in round numbers the following composition;—

Silicon.....	20	thousandths
Phosphorus.....	15	"
Carbon.....	35	"

The scoriæ or dross used contained, together with protoxyde and sesquioxyde of iron, from 17 to 22 per cent. of silica, from 4 to 10 per cent. of alumina and other bases, and from 1 to 3 per cent. of phosphoric acid.

After from 10 to 20 minutes of heating the mixture in a molten state at a low temperature, the pig iron contained only—

	Per cent.
1.2 thousandths of silicon.....	Loss 96
2.3 " phosphorus.	Loss 83
3.1 " carbon.....	Loss 11

The above experiments have demonstrated that ferrous scoriæ can be brought to contain as much as 6 per cent. of phosphoric acid, this proportion being considered as the extreme limit of saturation.

Mr. Bell has stated no figures as to the cost of such a mode of operation, which was still in the first period of experimentation; but in spite of the great proportion of oxides of iron employed, metallurgists have viewed with the greatest interest this process for the purification of pig iron in the *liquid state*, and we may be justified in believing that progress has been made since Mr. Bell's communication of March last.

Doubtless, the proportion of oxides might be less if the oxidation of phosphorus were assisted by a kind of preliminary refining (mazeage) in an easily managed mechanical furnace like that of Godfrey & Howson. But in order to be able to prolong the period of dephosphoration, *i.e.*, the elimination of the phosphorus, without the iron assuming what is termed the red, porous and nascent state, it would be necessary to use pig iron containing sufficient carbon to maintain the metal in the molten condition after the removal of the phosphorus; and if the proportion of carbon should be lowered too much proportionally to

* The analyses of cast iron containing an average of phosphorus at Thy-le-Chateau showed 20 thousandths of carbon and 24 thousandths of phosphorus; but the proportion of the latter element rises as high as 35 and even 40 thousandths in the more common cast iron of that locality. The iron obtained in the ordinary puddling furnace, working at high temperature with carbonate of lime and dross, contains 1 thousandth of carbon, from 1 to 2 thousandths of sulphur, and from 4½ to 8 thousandths of phosphorus.

the duration of the operation lengthened by the impurity of the pig iron, one ought to be able to restore carbon to such pig iron, and thus follow the same path as Dr. Parry, who proposed and carried into practice the *progressive mode of purification*, operating in turns by the oxidation of the carbon, and its restoration. Dr. Parry, however, proceeded by puddling, which transforms cast iron into a metal in the *solid state*, while the shingling press rids it of still more or less liquid scoria. Afterwards the metal was melted in a cylindrical furnace, supplied with two or more sets of tuyères, and supplied again with carbon by means of sufficiently pure coke with an excess of castine, to enable it to undergo a second refining in a Bessemer converter. But the cast iron had lost its silicon, which is first oxidised in the refining process, and it was absolutely necessary to add half-hematite pig iron, containing a great deal of silica, to render the operation possible.

Mr. Bell insisted on the necessity of keeping at the lowest temperature the molten iron from which phosphorus is about to be eliminated. For iron has a great affinity for phosphorus, and one should remember that that affinity no doubt increases with the temperature and degree of fluidity of the metal. The results, which are negative as far as dephosphoration is concerned, obtained in the Bessemer converter as well as on the hearth of a furnace heated at a high temperature, clearly demonstrate that phosphorus, in a very hot metallic bath, combines with the iron, and remains alloyed with it.

There is an experiment, which many metallurgists have possibly made, that further demonstrates what has just been said—namely, that if we take a few blooms fresh from the puddling furnace, and which have not yet passed through the shingling press, and these are charged in the bath on the hearth of a Siemens' furnace, the phosphorus contained in the scoria interposed in the blooms entirely passes into the metal. But another hypothesis was formed by Professor Grüner. It is to this effect, that in presence of silica, or of an acid silicate, containing at least forty per cent., the base of the scoria combines with the silica, setting at liberty the phosphoric acid, which is again taken up by the iron, forming with it a phosphide of iron. Mr. Pourcel, the chief of the Steel Works at Terre-Noire, is still more positive, in a recent paper, in asserting his belief that even with a silicate containing less than thirty per cent. of silica, iron decomposes the alkaline phosphates, and combines with the phosphorus. The immediate separation of purified cast iron, and of the phosphate produced, is absolutely necessary to effect the ultimate purification, because the contact of the liquid metal and the scoria containing phosphorus brings the metalloid back into the metallic bath. Mr. Pourcel dwells, therefore, on this fact, viz., that phosphorus leaves iron under the influence of an oxidizing action, coupled with the affinity of an energetic base, but that when *liquid* iron is left with the phosphates produced, the inverse reaction takes place, and the phosphorus combines again with the iron; while in the puddling process the dephosphoration is almost complete, even at a high temperature, provided, of course, the scoria is rendered entirely fluid through the presence of oxide of manganese.

Many processes have been proposed and tried to effect more completely the removal of phosphorus from cast iron during the operation which brings it back to the solid state. It would take too much space to examine them all in this short paper, but I may be allowed to mention a few of them.

Several inventors have tried either steam, which on dissociation yielded hydrogen, or some other hydrogen compounds, in the hope that phosphide of hydrogen would be generated, and then, owing to its volatility, be carried off by the gaseous current of the apparatus. But practical experiments have shown nothing of the kind, and it is very doubtful whether the hoped-for reaction could take place, on account of the instability of hydrophosphides, seeing that phosphorus has a far greater affinity for oxygen.

In other experiments, a series of pulverized substances have been injected into the bath. These were carbonates and other alkaline salts, sea-salt, dioxide of manganese, hypochlorites, fluor spar, borax, nitrate of soda and many others. Among these experiments, those that

were made according to Heaton's process deserve to be specially mentioned.

This process is based on the use of nitrate of soda, which has an action that is oxidizing and basic at the same time. The salt passes in minute jets through the cast iron, and a few minutes afterwards a metal is obtained which coagulates in the movable crucible of the apparatus. The results obtained form a very complete memoir, written in 1869 by Mr. Grüner, and showing that the experiments justify my stating the following facts:—

Silicon and manganese underwent oxidation before phosphorus, and carbon resisted more than any other foreign substance, this latter metalloid being disengaged in the state of carbon dioxide. In spite of the insufficiency of the proportion of nitrate used, two-thirds of the phosphorus were eliminated, partly in the shape of phosphate of soda, and partly (this being the greater portion) in the form of vapors, more or less oxidized, of phosphorus and phosporic acids. The powerful disengagement of oxygen produced, therefore, an intermolecular blast, which eliminated in the gaseous state the major part of the phosphorus that had disappeared. This is an indication not to be lost sight of.

Only a few weeks ago, Mr. Escalle laid before the congress of the Society of Mineral Industry the results of trials which he had just made with the mechanical puddler of Godfrey & Howson, heated by gas at a certain pressure. Those results confirm the indication formerly supplied by Heaton's process, namely, that the greater part of the eliminated phosphorus escaped with the gaseous current, probably in the form of dust of phosphates of iron, carried off by mechanical means, as Mr. Pourcel justly concluded.

The above trials had not yet led to a normal working of the puddler, so that it is not yet possible to consider with any certainty the exact value of the figures given as to the proportion of phosphorus eliminated—figures which stand far below those that result from other mechanical puddlers. It is now pretty generally admitted that mechanical puddling, wherein the flame passes through the mass of metal, leads to a higher degree of purification of the said metal, both as regards phosphorus and the other hurtful foreign matters.

Before ending this paper, it becomes my duty to particularly point out the conditions under which steel may be manufactured by means of Ponsard's fornoconvertisseur in each of the two following hypothesis:

1st. Either by the use in that apparatus of metal obtained from pure ores, like those of the two processes in use; or, 2d, by the use of metal obtained from impure ores, like those of the Moselle and Cleveland.

In the former hypothesis, and in comparison with the Bessemer process, the new apparatus appears to offer the following advantages:

1. The possibility of using cast iron containing but little silica and carbon.
2. The possibility of dissolving into the cast iron bath, previous to the use of blast, a quantity of waste or old metal far superior to that available by the transformation of ingots into bars.
3. Greater facility for obtaining the quality of steel sought.
4. Economy in the installation of plant when average importance only is expected in the matter of production.

In comparison with the Martin-Siemens process, Ponsard's fornoconvertisseur posesses obviously the following advantages:

1. The possibility of operating upon cast iron alone, or on a mixture containing but little iron.
2. Economy of fuel on account of the greater rapidity of the operation and the use of intermolecular heating; and,
3. Economy in the outlay for plant, since each apparatus, of equal dimensions, will produce at least twice as much in the same time.

In the case of the second hypothesis, namely, when operating on matters obtained from impure ores, the use of the fornoconvertisseur is subordinate to the success of the processes of dephosphoration, some of which have been mentioned in this paper.

First of all, it is to be noticed that in case the liquid process advocated by Mr.

Bell for the elimination of phosphorus should prove successful, the cast iron obtained could no longer be successfully worked because it would have lost its silicon, whereas it could be successfully treated in the fornoconvertisseur, under more favorable conditions than in the Martin-Siemens process.

In the instances where practice would sanction Barry's process, which is based upon progressive purification, the purified pig iron could not, any more than in the preceding case, be treated in Bessemer's process. The means which have been proposed for the use of powdered or gaseous reagents are easily applied to the fornoconvertisseur, since the system of injection is successfully adapted to it. It might be necessary, during a portion of the operation, to lower for a while the temperature of the bath, but this could be easily done by mixing a certain quantity of steam with the air injected through the mass of molten metal. Moreover, the new apparatus is well calculated to accomplish, without any external help, the partial removal of the phosphorus by mechanical action, as stated in the experiments according to Heaton's process and Howson's puddling process. Indeed, one can not only send a cold blast through the molten metal, but we can also send, under a greater or less pressure, a current of hot air through the burners of the gas furnace. This current will surround the drops of metal raised by the blast issuing from the bottom; and thus in addition to the oxidation of the phosphorus and the mechanical removal of its oxides, the complete refining of the metal will be effected better than by the Bessemer process.

The new apparatus appears, therefore, calculated to hold a distinguished place in the iron manufacture as soon as it has received the sanction of practical application.

REPORTS OF ENGINEERING SOCIETIES.

THE AMERICAN INSTITUTE OF MINING ENGINEERS have kindly forwarded advanced sheets of the papers read at the Pittsburgh meeting in May. They include:

The Tessie Gas Producer, by A. L. Holley, C. E.

Accidents in the Comstock Mines, by John A. Church.

Some Curious Phenomena Observed in Making a Test of Bessemer Steel, by William Kent, M. E.

The Use of Determining Slag Densities, by Thomas Macfarlane.

On the Wear of an Iron Rail, by W. E. C. Coxe.

An Apparatus for Testing Resistance to Repeated Shocks, by William Kent, M. E.

Working of Three Hearths at Cedar Point Furnace, by T. F. Witherbee.

The New Mining District at Sullivan, Me., by C. W. Kempton, M. E.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—The June number of the Transactions, which is just at hand, contains one paper, No. 181.

Flexure and Transverse Resistance of Beams, by Chas. E. Emery.

THE eighteenth annual meeting of the North British Association of Gas Managers has been held at Edinburgh, under the presidency of Mr. Alex. Smith, of Aberdeen, who, in the course of his address, gave it as his opinion that gas was hardly yet beyond the age of its infancy, and had nothing to fear from the electric light. Mr. Peter Watson, of Stirling, gave the results of his experience of the effects of frost on gas apparatus during the recent severe winter. Mr. Wm. Young, of Clippens, contributed papers on "The Elimination of Sulphur Compounds from Illuminating Gas" and "The Proportion of Carbon present in Gas in relation to its Illuminating Power." Mr. D. Bruce Peebles, Edinburgh, exhibited and described his needle gas governor; Mr. Esplin, of Forfar, spoke in favor of gas companies and corporations letting out meters to consumers free of charge; and Mr. Jas. Gilchrist, of Dumbarton, read an interesting paper on "Circumstances affecting the Price of Gas." A committee was appointed to confer with a committee of the West of Scotland Association of Gas Managers, with a view to the amalgamation of the two societies. Mr. Jas. Reid, of Haddington, was elected president for the ensuing year. Subsequently, Mr. Thompson, of Messrs. Laidlaw & Sons, read a paper on "A Gas-Compressing Engine for the Recovery of the Volatile Fluids in Waste Shale Gases." Mr. Wm. Cowan, of Edinburgh, exhibited and explained his automatic pressure charger, a machine which is intended to do automatically an important part of the work hitherto performed by the gas manager or his deputy. Next annual meeting was fixed to be held at Perth.

THE INSTITUTION OF CIVIL ENGINEERS.—The Council have awarded the following premiums in respect of original communications submitted during the Session 1878–79:

For Papers Read at the Ordinary Meetings.

1. A Watt Medal and a Telford Premium to George Frederick Deacon,* M. Inst. C. E., for his paper on "Street Carriage-way Pavements."

2. A Telford Medal and a Telford Premium to John Bower Mackenzie, M. Inst. C. E., for his paper on "The Avonmouth Dock."

3. A Watt Medal and a Telford Premium to James Nicholas Douglass,* M. Inst. C. E., for

his paper on "The Electric Light Applied to Lighthouse Illumination."

4. A Telford Medal and a Telford Premium to Adam Fettiplace Blandy, M. Inst. C. E., for his paper on "Dock Gates."

5. A Telford Premium to Edward Dobson, Assoc. M. Inst. C. E., for his paper on "The Geelong Water Supply, Victoria, Australia."

6. A Telford Premium to James Price,* M. Inst. C. E., for his paper on "Movable Bridges."

7. A Telford Premium to John Evelyn Williams, M. Inst. C. E., for his paper on "The Whitehaven Harbor and Dock Works."

8. The Manby Premium to John Purser Griffith, Assoc. M. Inst. C. E., for his paper on "The Improvement of the Bar of Dublin Harbor by Artificial Scour."

For Papers Printed in the Proceedings Without Being Discussed.

1. A Watt Medal and a Telford Premium to George William Sutcliffe, Assoc. M. Inst C. E., for his paper on "Machinery for the Production and Transmission of Motion in the large Factories of East Lancashire and West Yorkshire."

2. A Watt Medal and a Telford Premium to Edward Sang, for his paper on "A Search for the Optimum System of Wheel Teeth."

3. A Telford Premium to William George Laws, M. Inst. C. E., for his paper on "The Railway Bridge over the River Tyne at Wylam, Northumberland."

4. A Telford Premium to George Higgin,* M. Inst. C. E., for his "Experiments on the Filtration of Water, with some Remarks on the Composition of the Water of the River Plate."

For Papers Read at Supplemental Meetings of Students.

1. A Miller Prize to Arthur Cameron Hurtzig,† Stud. Inst. C. E., for his paper on "The Tidal Wave in the River Humber."

2. A Miller Prize to Robert Henry Read, Stud. Inst. C. E, for his paper on "The Construction of Locomotive Boilers."

3. A Miller Prize to John Charles Mackay,† Stud. Inst. C. E., for his paper on "The Excavating of a Tunnel in Rock by Hand Labor and by Machinery."

4. A Miller Prize to Percy Wilson Britton,† Stud. Inst. C. E., for his paper on "The Design and Construction of Wrought-iron Tied Arches."

Through the politeness of Mr. James Forrest, A. I. C. E. Secretary, we have received the following published papers of the Institution of Civil Engineers:

Movable Bridges, by James Price, M. I. C. E.

Irrigation in Ceylon, by Henry Byrne, M. I. C. E.

The St. Gothard Tunnel, by Daniel K. Clark, M. I. C. E.

Technical Report of the German Railway Union, by Walter Raleigh Browne, M. I. C. E.

The Electric Light Applied to Lighthouse Illumination, by James Nicholas Douglass, M. I. C. E.

*Have previously received Telford Medals.
†Have previously received Miller Prizes.

Dioptric Apparatus for Electric Light in Lighthouses, by James T. Chance, A. I C. E.

IRON AND STEEL NOTES.

A NEW RAIL-BENDING MACHINE.—E. Schrabetz has supplied a long-felt want by his invention of a simple machine for bending rails, which has proved to be very effective in numerous cases. Six rails are laid on a platform alongside each other, the first of the six being the one to be bent, while the five others serve as a fulcrum or foundation for the work. First, both ends of all the rails are fastened together by a U-shaped clip, which passes over the outside of the sixth rail, and has a lug cast on its inner edge which fits into the bolt hole of the rail and thus prevents its slipping. The two branches of the U are then screwed together behind the first rail by a bolt. The ends of all the rails being thus rigidly connected, lateral slipping is avoided by a number of small chocks which fit into the flanges of the rails and are placed between them, each chock having an eye through which a bar can be passed for convenience of inserting or extracting it. At a distance of about 3 feet from either end a small machine, resembling and constructed on the same principle as a bottle-jack, is then inserted horizontally between the fifth rail and the one to be bent. It is clear that when the bottle-jacks are turned by a forged hooked lever, specially made for the purpose, their heads will force the outer rail out, and as its ends are secured they will bend it to a curve.

ANOTHER DIRECT PROCESS OF MAKING IRON. — The *American Manufacturer* speaks of a new direct process which has been introduced at Brady's Bend, Pa. The furnace used is shaped like an ordinary blast furnace for making pig iron, a hot blast is used, and by an attachment at the base the product may be made directly into wrought iron without going through the indirect process of prior conversion into pig or cast iron; or, if desired, a partial carbonization can be effected and the product will be cast steel. The wrought iron is obtained in the shape of balls similar to puddled balls, but made without puddling, the balls being made in the attachment at the bottom of the furnace. If steel is desired, the material will be heated to fusion in this same attachment. The whole process is perfectly under control, and the economy, it is claimed, is such that a ton of wrought iron has been made with the expenditure of less than a ton of fuel. The cheapest kind of solid fuel is used—viz., coal slack. The ores employed are found in the vicinity of Brady's Bend, and are reported to be of poor quality. The *Manufacturer* is not at liberty to publish full particulars, or the name of the inventor, but expresses an opinion that the invention appears to be the best of all the direct processes, and that it may not unlikely prove to be the most important improvement in the metallurgy of iron since Neilson's invention of the hot blast.

THE statistics of British iron and steel exports for the month of June and the first

six months of the year have been received. The export of railway iron in June were 40,992 tons, against 51,198 tons in June, 1878, and 63,970 tons in June, 1877. The United States increased its importation from 19 tons in June, 1877, to 312 tons in June, 1878, and to 4,834 tons in June, 1879. The exports of railway iron in the first six months of this year aggregated 209,599 tons, against 247,805 tons in the first six months of 1878, and 228,480 tons in the first six months of 1877. The exports to the United States in the first six months of 1877 were 2,502 tons; in the first six months of 1878 they were 464 tons, and in the first six months of 1879 they were 7,738 tons. The total exports of all forms of iron and steel aggregated 194,628 tons in June, 1879, against 210,993 tons in June, 1878, and 223,055 tons in June, 1877. The total exports of the same commodities in the first six months of 1879 were 1,213,628 tons, against 1,127,698 tons in the first six months of 1878, and 1,118,183 tons in the first six months of 1877.

THE GERMAN IRONMASTERS' ASSOCIATION AND THE NEW DEFINITIONS OF IRON AND STEEL.—At the Philadelphia Exhibition, it will be remembered, an International Committee, consisting of commissioners who were over reporting for the different countries, had a discussion on the classification of iron and steel, and proposed new definitions. Among those on the committee were Mr. I. Lowthian Bell, M.P., F.R.S., and Dr. Reuleaux, of Berlin. The German Ironmasters' Association has just had this classification under discussion, and resolved:—(1), That a general classification of iron and steel is neither necessary nor useful; (2), that the tests now customary for testing iron and steel goods—hammering, bending, and loading for rails, bending for axles, pulling for sheets, &c.—are sufficient; (3), a specification of limits of value of the properties of iron and steel goods in reference to their uses is desirable; (4), that a further prosecution of the experiments hitherto conducted by the Association, with common commercial irons, is therefore desirable, in view to an eventual special classification of railway material; (5), that State testing be placed under the control of a commission, consisting, on the one part, of delegates chosen by consumers and producers alike, and, on the other, of approved men of science; (6), quantities of metal in railway contracts to be determined by ironmasters conjointly with the railway engineer; (7), that the proposal made by Dr. Reauleaux, to draw up a table of properties, and stamp goods with a mark corresponding to a designation in the table is impracticable.

RAILWAY NOTES.

THE Philadelphia and Reading Railroad Company, in the statement contained in its report for 1878 of locomotives then owned, mentions six engines over thirty-five years old. Of these No. 1 weighs 11.8 tons, was built by Brathwaite & Co., London, ran 6053 miles last year, and is still at work on the Richmond coal wharves; in its forty-one years' service it has made 310,164 miles. No 2, also from Brathwaite & Co., weighs 12.1 tons, and is reported as "out of service—to be rebuilt," but it made 3398 miles last year, and has run 334,789 miles since May, 1838 No. 4, built by the New Castle Company in 1842, weighs 13.8 tons, and ran 1628 miles last year, having made but 154,776 miles in its thirty-seven years of life; it is now out of service and to be rebuilt. No. 6, weighing 14·1 tons, built by the Locks & Canals Company, of Lowell, Mass., in 1843, is reported as still in service, assorting cars at Schuylkill Haven; it is credited with 7138 miles in 1878, and 323,164 miles in all. Nos. 7 and 8, also built by the old Locks and Canals Company in in 1843, weigh 14.8 tons each, and are credited with 243,849 and 308,785 miles respectively. Both are now out of service, though No. 8 ran 6155 miles last year. The highest average mileage per year of any of these engines was 8850 miles made by No. 6. Other engines on the road, however, have made a much larger average mileage, the highest among the older engines being that of No. 58, which has averaged 31,823 miles a year. This engine was built at the company's Reading shop in 1859, and last year made 54,600 miles in passenger service on the East Pennsylvania and Lebanon Valley branches.

THE roads which are controlled by the President, the celebrated Vanderbilt, of the New York Central and Hudson River—he is president of all, except three, which have together 640 miles of road—have an aggregate length of 3620 miles of road and 6102 miles of track. On these were employed, according to the *Railroad Gazette*, by recent pay-rolls, 27,706 men, who receive, in round numbers, $1,178,000 per month, or more than $14,000,000 per year. There is probably but one other case in the world where so many men are under the orders of a single man not an army officer or Government official. The number is somewhat greater than that of the United States army as it now stands. The roads on which this force is employed, the mileage of road and of track, &c., are as follows;

	Miles of road	Miles of track.	Total men.	Monthly pay-roll.
				$
N. Y. Central and Hudson River..	866..	2277..	10,728..	465,000
N. Y. and Harlem.	134..	195..	870..	37,000
Lk. Shore & Michigan Southern...	1176..	1874..	8052..	398,000
Canada Southern.	443..	460..	1661..	65,000
Michigan Central.	804..	1068..	4850..	188,000
D'nkirk, Allegh'ny Val. & Pittsb'gh.	90..	101..	380..	14,000
Rochester & State line.....	107..	118..	265..	11,000
Total.....	3620	6102	27,706	1,178,000

The aggregate amount of capital stock of these corporations is $186,116,504.

ENGINEERING STRUCTURES.

THE BROOKLYN BRIDGE CONTRACT.—*Condensed from the Philadelphia Times.*—The

Edgemoor Iron Company has been awarded the great contract for supplying the trustees of the New York and Brooklyn bridge with 10,728,000 pounds of Bessemer Steel and 34,000 pounds of iron. The president of the company, William Sellers, is the head of the firm conducting the well known machine works of William Sellers & Co., as well as president of the company that controls the Midvale Steel Works at Nicetown. The Edgemoor Iron Works are on the right bank of the Delaware river, about half a mile from Edgemoor Station, on the Philadelphia, Wilmington, and Baltimore Railroad, and three miles north of the railroad depot in Wilmington, Delaware.

The bids for the Brooklyn bridge supplies were as follows:—Chrome Steel Company, price per pound, 8.25 cents for steel, 4 cents for iron; total, $886,420. C. P. Haughina, 7.75 cents a pound for steel, 4.05 cents a pound for iron; total, $832,950. Keystone Bridge Company, 4.394 cents for steel, 5 cents for iron; total, $473,258.32. New Jersey Steel and Iron Co., 5.74 cents for steel, 18.3 for iron; total, $622,009.20; for punched steel, $599,480.40. Delaware Bridge Company—total, $483,218.80 for Bessemer compressed steel, and $553,166.80 for Hay compressed steel; Cofrode & Saylor, Siemens-Martin and Hay steel, $643,567,60. Leighton Bridge Company, open-hearth-steel, $645,125; crucible steel, $854,321; Bessemer steel, $617,232. The bid of the Edgemoor Iron Company was 4.35 cents a pound for steel and for iron, making a total of $468,147.

Mr. William Sellers gave a *Times* reporter the following information about this great contract:

"By the terms of the contract we have to furnish only five hundred tons, or less than one-tenth of the whole quantity, before the 1st of next January. This contract will, therefore, make no perceptible stir in our works for some months yet. After a while the Midvale Steel Works, of which I am president, will begin to roll the shaped steel for the beams, girders, trusses, floor work, etc., required. The steel and iron that we are to supply are the entire quantity needed for the suspended superstructure of the bridge. After being rolled at the Midvale Works, the steel will be taken down to Edgemoor and there fabricated as desired. As the bridge trustees could not use more than the five hundred tons before the 1st of next May, we, of course, would not like to send a larger quantity. After January 1st the trustees will not be obliged to receive any more material until May 1st, and in case we shall receive no notice from the trustees before the latter date to furnish the remainder of the material, then, and until July 1st, 1881, we may, at our option, determine the contract as not obligatory, and after July 1st, 1881, the contract may be canceled by either of the parties. We desired such terms to insure protection for ourselves."

A representative of the Edgemoor Iron Works remarked last evening that the Brooklyn bridge is the second ever built whose suspended superstructure will be of steel. The first one is the truss bridge, completed about a month ago, across the Missouri river, on the Kansas City extension of the Chicago and Alton Railroad.

ORDNANCE AND NAVAL.

SINCE the middle of April the Neva has been free of ice, and marine traffic is resumed. Two large steamers are expected at Cronstadt shortly, which both as regards their construction and the voyage they have before them, present much that is interesting. They are for service on the Caspian Sea, have about 8ft. draught of water, and have been built at Rostock of steel, including the decks and the lower masts. (The steel was supplied from the Rhine Westphalian works). The boilers are heated with petroleum. Not with raw naphtha, which exists in inexhaustible supply in the Baku province, but with the heavy hydro-carbon which forms a residue after the refining process. The steamers come to Stettin in January, to take cargo for St. Petersburg, thence to make the voyage through the country to their destination. Their course will be (briefly) as follows: From St. Petersburg to Schlüsselberg, then across Lake Ladoga to the mouth of the river Swir, or by the Maria Canal system from Schlüsselberg, south of Ladoga, to the Swir. This river is connected with the river Witegra, which flows into Lake Onega by the Onega Canal; then the course is up the Witegra into the Maria Canal, and so into the Bjeloserski Canal, which opens into the river Scheksna; then down the Scheksna to the Volga, near Rybinsk, whence the course of the Volga is pursued to its mouth, at Astrachan, in the Caspian Sea.

SOME further details have been lately published of the cost of the four enormous ironclads which are being constructed for the Italian Navy. The Duilio, of 10,570 tons displacement and designed to carry four 100 ton guns in two turrets, was launched at Castellamare in 1877, and is now so far advanced that she will be ready to receive her armament before the end of the present year. It was originally estimated that she would cost 17,000,000 lire—£680,000; but it is now found that the expense of her construction will be more than 18,000,000 lire—£720,000. The Dandolo, a sister-ship of the Duilio, was launched last year at Spezzia, is now having her machinery placed in her, will be ready to receive her guns towards the end of 1880, or the beginning of 1881, and will cost very nearly as much as the Duilio, or a trifle under £720,000. The other two ships, the Italia and the Lepanto, which are even larger than the Duilio, being each of 13,700 tons displacement, or some 2000 tons larger than the Inflexible, are at present still on the stocks, but it will, it is hoped, be ready for launching next year. The cost of each of these vessels was originally estimated at 17,000,000 lire—£680,000; but will, it is now calculated, amount to 19,720,000 lire—£788,800. The four ironclads will, therefore, together cost 9,306,000 lire—£372,240—more, says the *Pall Mall Gazette*, than was at first anticipated; but it must be added that there is some slight, though apparently by no means well founded,

hope entertained that it may be found possible to armor the Italia and Lepanto, with plates of cheaper manufacture than those placed on the Dandolo and Duilio, whereby a saving of about 2,000,000, lire—£80,000—would be effected in the total cost of each ship.

BOOK NOTICES

TURBINE WHEELS. (Van Nostrand's Science Series). By Prof. W. B. TROWBRIDGE, Columbia College. New York: D. Van Nostrand. Price 50 cents.

The reading of a sound practical memoir frequently leads one to study the subject dealt with, although otherwise it would be neglected by him, and this observation is particularly applicable with regard to the memoir on turbine wheels by Prof. Trowbridge, of Columbia College, New York, which has just been reprinted from VAN NOSTRAND'S ENGINEERING MAGAZINE, the object of the memoir being to show the inapplicability of the theoretical investigations of the turbine wheel as given by Rankine, Weisbach, Bresse, and others to the modern constructions introduced by Boyden and Francis. The professor, after correcting an important error in former treatises on hydraulic motors, explained how the best practical results have been obtained by modern engineers who have discarded the formulas of the old standard works. He remarks that if Boyden and Francis had followed strictly the rules of construction laid down in the works alluded to they would have failed in their efforts to construct turbines giving any considerable increase of efficiency over the old Fourneyron and Fontaine or Jonval wheels of European design and construction. The theorem insisted on by the writers in question was that "the water must enter the wheel without shock," and hence the mathematical condition of the tangential velocity of the wheel where it receives the water, and the corresponding component of the velocity of the entering water must be equal, the effect of which is to prevent all impulsive effects of the entering water. In the old Fourneyron wheel the effects of the water in producing mechanical work were thus made to depend solely upon the subsequent deviation which is experienced in passing through the wheel.

It is to be noted, says Prof. Trowbridge, that both Rankine and Weisbach, in discussing the impulse and reaction of jets of water upon moving vanes, make no reservation in regard to the shock due to impulse, but demonstrate that water may impinge at any angle and with any relative velocity upon vanes, and by a suitable arrangement of curvature and velocities may have all the energy destroyed, and a perfect efficiency may be obtained. It is, he continues, difficult to understand why in the discussion of the turbine-wheel they insist on a different principle, and lay down a mechanical axiom at variance with these demonstrations. An unnecessary importance seems to have been attached to the idea that a stream of water to produce its best effect upon a vane or float must glide upon the latter in a tangential direction. He directs a very simple experiment to demonstrate this, which requires no other apparatus than a goblet and a goose-necked tube. In conclusion, Prof. Trowbridge states that the general principles to be kept in view for all buckets are—That the channels between the buckets shall not have abrupt changes in direction; that they shall be as short as possible; that the curvature of the buckets shall be continuous; that the discharging edges of the buckets shall have a uniform discharging angle; and that the cross-section of the channels between the buckets shall be uniform throughout. It is especially important that the water should leave the guide-blades and enter the wheel in clear transparent streams without contraction, in order that these streams may continue unbroken through the wheel to the point of discharge. The value of the information given by Prof. Trowbridge cannot be over-estimated, and the memoir should be carefully studied by every engineering student.

ANNUAL REPORT OF THE CHIEF SIGNAL OFFICER FOR THE YEAR 1878. Washington: Government Printing Office.

The work under direction of Gen. Myer, is regarded with interest and pride by every intelligent citizen.

The importance of it is no longer questioned, and the Report assures us that the subordinate officers are improving in zeal and efficiency. There is no difficulty in finding recruits for such vacancies as occur from among the most intelligent classes of the country.

It must inevitably happen that from this systematic plan of observing and recording meteorological changes there will come a better knowledge of the laws governing them, and that the honor of contributing to such knowledge will belong in the largest degree to our own Meteorological Bureau.

CANAL AND CULVERT TABLES BASED ON THE FORMULA OF KUTTER. By LOUIS D. A. JACKSON, A. M., I. C. E. London: William H. Allen & Co. Price $10.00.

After a discussion of Kutter's formula and the range of its application, the author has compiled for convenient use, tables of which the following is a synopsis:

I. Formulas, Symbols and Values of Variables; II. Coefficients of Mean Velocity; III. Values of the Expression $100\sqrt{RS}$; IV. Sectional data for Culverts and Canals; V. Mean and Maximum Velocities; VI. Results for Glazed or Cemented Pipes; VII. Results for new Culverts Brick, Iron or Cement; VIII. Results for Canals of Rectangular Section; IX. X. XI. Results for Canals in Earth of Different Kinds; XII. Results for Reduction, Multipliers, etc.

The work which is in a fine royal octavo form closes with Examples and Calculations.

FOUNDATION AND FOUNDATION WALLS. By GEORGE Y. POWELL. New York: Bickwell & Comstock. Price $1.50.

The title of this work is suggestive of practical hints upon a relatively much neglected subject.

The authors, for there are two, Mr. Baumann,

an architect, contributing two chapters of valuable hints on foundations for houses—are practical and brief to the last degree.

The work will prove of great value to young engineers by calling attention to the first and most obvious principles of bases for superstructure, and to the engineering services by which common obstacles are overcome.

The properties of all the various materials in use for bases are fully discussed, and the methods of starting the superstructure from the prepared foundation described and illustrated.

L'ELAIRAGE ELECTRIQUE. Par LE COMTE TH. DU MONCEL. Paris: Librairie Hachette et Cie. Price 90 cts.

This work presents a complete history of Electric Lighting, including the so-called lamps and their regulators down to the present year. The principal magneto-electric machines are also described and finely illustrated.

The name of this celebrated author is a sufficient guaranty of the accuracy of the information afforded by this compact essay.

THE TELEPHONE, THE MICROPHONE AND THE PHONOGRAPH. By COUNT DU MONCEL. Authorized translation. London: C. Kegan Paul & Co Price $2.00.

This is a translation of the work mentioned among our Book Notices some two or three months ago. The various forms of these instruments are beautifully illustrated, including all down to the time of the publication of the original French work.

The later form of Edison's telephone has appeared since, and is not therefore noticed even by the translator.

MISCELLANEOUS.

IRON ON THE PHILADELPHIA AND READING RAILROAD.—The Philadelphia and Reading Railroad Company is testing the utility of iron crossties instead of wood sleepers, near its depot at Phœnixville.

LOCOMOTIVES ON THE CHICAGO, MILWAUKEE AND ST. PAUL RAILROAD.—It appears that twelve additional locomotives were placed upon the Chicago, Milwaukee, and St. Paul Railroad in 1878. The company's stock of engines was thus increased to 226.

FRENCH RAILWAY WORKING EXPENSES.—The ratio of the working expenses to the traffic receipts on the old network of the Paris, Lyons, and Mediterranean Railway was brought down last year to 36.03 per cent. The corresponding ratio in 1877 was 37.08 per cent.

GOLD IN RUSSIA.—The St. Petersburg papers report a great development of the gold production of Russia. Strata containing gold in considerable quantity have recently been discovered in the Ural Mountains. It is said that in the district of Sennigsei, a Russian proprietor has found gold in his gold mine, near Motygynn, a nugget 445 lb. in weight, representing a value of nearly £15,000.

INDIAN CITIES.—British India has 44 cities counting 50,000 inhabitants and upwards, the most populous ones being: Calcutta, 892,429; Bombay, 644,405; Madras, 397,552; Lucknow, 284,779; Benares, 175,188; Patna, 158,900; Delhi, 154,417; Agra, 149,008; Allahabad, 143,693; Bangalore, 142,513; Amritsur, 135,813; Cawnpore, 122,770; Pouna, 118,886; Ahmedabad, 116,873; Surat, 107,149; Bareilly, 102,982; Lahore, 98,924; and Rangoon, 98,745.

COAL IN VICTORIA.—There have been so many announcements of the discovery of paying seams of coal in Victoria, all of which have proved to be failures, that any fresh notification of such a discovery is looked upon with suspicion. It is, however, now said that a fine seam of coal, at least 2 feet 6 inches thick at the outcrop, has been discovered at the Moe, about two miles from the Gippsland line of railway. A company is being formed to test the discovcovery.

AMERICAN BRIDGE RESTORATION.—Owing to their immense weight, the iron shoes in which rest two of the spans of a long railroad bridge at Easton, Pennsylvania, lately sunk about an inch, throwing the bridge out of grade. As it was certain that the depression would continue, owing to the fact that the inside masonry of the pier is less solid than the outside, an iron casting 12 feet long, 3 feet 3 inches wide, and 3 inches thick, weighing 7000 lbs., was recently successfully placed under the spans in order to elevate them. The spans weigh 180 tons each. Hydraulic jacks were used. The spans were raised, the masonry redressed, the castings placed in position, and the spans lowered without the stoppage of a single train.

A GOOD example of what can be done in the utilization of waste foreshore lands by private enterprise, is the recent reclamation of about 750 acres at Pagham on the Sussex coast. The first step taken was to make an embankment or sea-wall and to get the soil drained into an open bed in the center of the area, the outlet of which is controlled by a sluice automatically closed at high water. The process of cultivation was first attempted with horses, but the soil of a great part of the reclaimed land is close and muddy, and an essential to successful culture is to loosen and lighten the top soil so as to admit the air and sun. After ploughing and harrowing with horses a shower of rain caused the land to run together, and it was then decided to apply steam power to the work, so as to lift up and thoroughly loosen the soil to a depth of 10in. The land thus treated keeps light and does not run together again, and the condition of the corn plant sown on lands thus treated by steam power is remarkably superior to that on the same class of land worked by horse power. The character of the soil makes it impossible to travel engines over it. At Barth, on the Welsh coast, similar operations were carried out a few years ago, and as Messrs. Howard's steam tackle was used there the proprietor resolved to adopt it at Pagham. The engine is placed on a road which has been made alongside the reclaimed lands, the ropes being passed round the piece to be cultivated, two traveling anchors taking the place of two men. During the passed season a large number of acres were ploughed and cultivated in this way, and the corn sown there is now ripening for the sickle.